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LIPPINCOTT'S PHYSIOLOGIES

THE THIRD BOOK
OF
ANATOMY, PHYSIOLOGY
AND
HYGIENE
OF THE HUMAN BODY

BY

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PHILADELPHIA AND LONDON
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We, the undersigned, have carefully read Book III. of the Lippincott Physiologies, and are happy to note the full and adequate teaching of the physiological reasons for obeying the laws of health, including those that relate to the nature and effect of alcoholic drinks and other narcotics upon the human system which this book contains.

The truths taught are well told in language adapted to pupils in elementary and secondary schools, for which we heartily recommend the book.

Mary H. Hunt,

Life Director of National Educational Association; National Director of Bureau of Scientific Temperance Investigation, and World and National Superintendent of Department of Scientific Temperance Instruction of the Woman's Christian Temperance Union.

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PREFACE

THIS is the last book of a series of three. It is the most advanced of the three, and is complete within itself. It is intended to embrace the facts in anatomy, physiology, and hygiene which every man and woman should know.

Every effort has been put forth to make the subject *plain* to the reader. This is important in a subject of this kind. A lack of interest very frequently arises from the inability to grasp an idea as it is presented, though it may be simple enough when presented in a different way.

The body is treated as an organized unit, each part having a function, and all parts being related to the others and dependent upon the harmonious operation of all. The division of labor among the organs of the body is often so sharp that a derangement of one tends to a disorganization of the whole body. This furnishes a strong basis for rules of hygiene and the consideration of the alcohol problem.

This book contains not only general statements, but exact information as far as possible. Technicalities may seem to be avoided by general statements, but the subject is thus often robbed of its interest and value. The red corpuscles are the carriers of oxygen, but in a book of this kind the function of the hemoglobin and its affinity for oxygen should be explained. Otherwise the pupil may get the idea, as in cases known, that the gas is carried in the concave depression of the corpuscle. This is an illustration of the many peculiar ideas which pupils form from only general statements.

Questions are appended at the end of each chapter. These are mainly topical. It is presumed that the teacher will add numerous questions in the nature of quizzes, as conditions may demand, but the best recitation is one in which a pupil discusses a topic in a connected discourse.

A list of experiments, such as may be performed in any school where this book is used, is found at the end of each chapter. The experiments are purposely few in number, being selected with the intention that not one of them need be omitted. It is better to give them from time to time during the study of the text, rather than all at once. The teacher will find it profitable to supplement the list with others when time and conditions permit. Nothing is so great an aid in making this subject interesting as experiments which are performed by teacher and pupils. Many experiments may be performed at home, and will be performed with zest by most of the class after they have had proper direction.

The subject of alcohol and its effect on the body has been treated in the light of modern investigation. The statements in regard to its effect are based upon a knowledge of the nature of the human organism, reliable experiments which have been made, and the experiences of the past.

The writer acknowledges his indebtedness to the J. B. Lippincott Company for many courtesies, and permission to use a number of cuts belonging to them. Also to S. R. Williams, professor of biology in Miami University, for many valuable suggestions and reading of manuscript, and to G. W. Hoke, professor of natural history in Miami University, for many helps and suggestions.

By permission of Ginn & Co. two cuts from Blaisdell's physiology are used in this text.

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THIRD BOOK OF PHYSIOLOGY

CHAPTER I

A GENERAL VIEW OF THE SUBJECT

Matter and life.—Man has always been interested in the study of his own body. It is natural for him to look about and make comparisons between other objects and himself. He observes that every known form of matter is either an inert, lifeless substance, as stone, iron, water, and air, or is organized and endowed with life, as in vegetables and animals.

The great bulk of matter is lifeless, but the small part that is endowed with life is of greatest interest and importance.

We do not know what life is, but we do know that it has a wonderful influence upon matter that is taken into the bodies of plants and animals.

We know that vegetables and animals are alive for three reasons: (1) They can take up lifeless matter called their food and can change it in such a way that it builds up and strengthens their own bodies. Only a live body can do this. (2) They can reproduce their own kind. They are both made up of small bodies called cells, and the cells can produce others just like themselves. The cells of a live body only can do this. (3) They can move. It is true a tree cannot move about bodily, but there is a constant movement within its cells, as will be explained in the next chapter.

Any body that can do these three things is alive.

Animals and vegetables.—Some minute organisms are of such a low order that it is not possible to tell whether they are animals or plants. In all the higher orders, however, there is a clear distinction between the animals and the plants.

(1) Animals have the power of voluntary motion of the whole body, while plants are fixed to one place.

(2) Animals feed on complex foods that have been prepared by plants, while plants feed on simple foods, such as minerals, water, and carbon dioxide.

(3) Animals have a distinct digestive tract within the body, while plant food is prepared in the green leaves.

(4) Animals are endowed with a distinct nervous system, to which plants have nothing to correspond. *Man is an Animal.*

Classes of animals.—The animal kingdom is divided in modern zoologies into twelve branches. The lowest branch includes the *Protozoa*. This word means *first life*, and is a general name for a group of the lowest kind of animals. All these are of very simple structure, and so small that they can be seen only by aid of the microscope. They may be found wherever there is water. During their lifetime they are composed of but a single cell, and yet they eat, breathe, move, feel, and reproduce like other animals, only in a very simple way.

From these lowest forms of the animal kingdom there is a gradual rise to higher and more complex forms. Many cells unite to form one body, and different kinds of cells form organs with special functions.

The highest branch of the animal kingdom is the *Vertebrates*. This includes all animals that have a backbone. *Man is a Vertebrate Animal.*

The vertebrates.—Vertebrate animals are of six kinds. (1) The *Cyclostomata*, a kind of eel without true bones, and with only a trace of a backbone. It gets its name from the fact that its mouth is circular and always stands open. The lamprey is an example of this class. (2) The *Fishes*. (3) The *Amphibia*, vertebrates which spend the early part of their life as tadpoles in water, such as toads and frogs. (4) The *Reptiles*. (5) The *Birds*. (6) The *Mammals*.

Mammals are distinguished by the hair on the body and by the mammary gland that secretes milk for the nourishment of their young. They also differ from the other vertebrates in having a midriff, or diaphragm, that separates the chest from the abdomen. *Man is a Mammal.*

The study of man.—We are about to study the wonderful structure and operation of the highest and most complex organism in which life resides,—the human body.

Scientists have investigated and experimented for many years to find out how the body is made and how it operates. While many things are yet without a satisfactory explanation, much is known with certainty, and with these things all should be familiar.

The more one knows the more he can do, and the greater is his pleasure, whether he reads, travels, works, converses, or communes with his own thoughts.

The chief object in this study, however, is that it may lead to the development of a sound and skilful body.

Man is capable of high development of both mind and body, but those who are ignorant of the principles of physiology and hygiene are apt to follow instincts, appetites, and passions rather than intelligence and reason. Although knowledge alone will not produce a sound body or a sound mind, yet the practice which should accompany knowledge is much more likely to follow when there is an intelligent basis for the manner and purpose of eating, breathing, sleeping, working, and study.

A healthy body and a vigorous mind are, as a rule, found together.

The great advantages of good health should furnish a sufficiently strong motive for understanding the conditions by which it can be secured.

The three divisions of the subject.—When a machinist undertakes to operate a machine with which he is not familiar, he first makes a study of it and tries to answer three questions :

(1) How is it constructed ?

(2) What is the use of each part, and how does it operate?

(3) How can it be made to operate most efficiently and keep in good running order?

The human body is a machine more complex and intricate than anything the mind has been able to devise. Many of its operations are automatic, but the whole body, either directly or indirectly, is placed under the control of the mind which resides within it. The freedom of choice makes each one responsible for his physical condition.

The three divisions of this subject are:

(1) *Anatomy*, a description of the construction of the body.

(2) *Physiology*, a description of the use and operations of the various parts of the body.

(3) *Hygiene*, a description of the conditions and laws of good health.

Anatomy.—The word *anatomy* is from two Greek words which mean, *to cut apart.* The act of cutting a body apart to determine the structure of its parts is called *dissection.* What we learn about the situation, structure, and adaptability of the various parts of the body is called the *anatomy* of those parts. For example, in giving the anatomy of the stomach we would tell its location in the body, its shape and size, its openings, its linings, and its relation to other organs.

Physiology.—The word *physiology* is made up of two Greek words which together mean, *a discourse on nature.*

The word is now applied to nature only as it is seen in animals and plants. In this book we shall study nature only as it is seen in man. The proper title of this book, then, is, The Physiology of the Human Body.

Physiology proper deals only with the *activities* of the various parts of the body. In giving the physiology of the stomach, we describe its movements and the effect of its secretions upon the food within it.

The term is also used in a broad sense including both anatomy and hygiene. In this sense it is used as a title of this book.

Hygiene.—The word *hygiene* is from a Greek word which means *health*. The name of the goddess of health in mythology is Hygeia Hygiene treats of the principles and rules which have for their object the promotion of good health.

Aids to the study of physiology.—All the sciences are very closely related, and each one helps to explain the others. Progress in the study of physiology has been possible only in proportion as the other great sciences have advanced.

The chemist can analyze the matter of the body and determine its composition. He can also determine the composition of foods and their adaptability to the needs of the body. He can follow the food in its circuit through the body and can note the changes it undergoes, thus determining the chemical function of the organ through which it passes.

Physics throws light upon the study of physiology in furnishing a clear knowledge of the mechanical principles employed in the body, the energy value of foods, and in showing that the body is a true machine.

Modern biology has been, probably more than any other science, a great source of information in regard to living nature in motion. The biologist is not satisfied with superficial knowledge, but searches for the basis of even life itself. The microscope has been a powerful instrument in his hands, and has opened to his view the structure and activity of the living cell. The subject of physiology cannot be clearly understood without a knowledge of the activities within the cell. For this reason the next chapter is devoted to a study of the cell.

REVIEW QUESTIONS.

These and similar sets of questions at the end of chapters should be assigned as definite lessons to be carefully prepared. The pupil is not ready to recite the review lesson until he can answer each question without turning to the text. It is a good plan in this subject, as in most others, to insist on having the first lessons very thoroughly prepared and understood. Successful preparation of the first lessons is sure to result in an interest in the subject and greater effort in the lessons that follow. Each succeeding chapter is written on the assumption that the preceding one has been mastered.

1. What are the proofs of life?
2. Is it proper to use the expression "live coal" or "live wire"?
3. How can you distinguish between animals and plants?
4. Is a dead ox an animal? What is it?

5. What is the lowest branch of the animal kingdom? What is their manner of life?

6. What is the highest branch?

7. Give in order the six kinds of vertebrates.

8. Give an example of each kind.

9. What does the word *amphibia* mean? (See dictionary.)

10. Name three things that distinguish mammals.

11. How does an animal differ from a brute?

12. What is man's position in the animal kingdom?

13. Of what advantage is a knowledge of physiology?

14. Does a body need to be large in order to be healthy?

15. What would you say of a strong body that was unskillful?

16. What are the three things a machinist must know about his machine?

17. What are the three divisions of physiology?

18. Define anatomy.

19. Define physiology.

20. Define hygiene.

21. In what broad sense is the term physiology often used?

22. What other sciences aid in the study of physiology?

23. Of what use is the microscope in this study?

24. What is biology? (See dictionary.)

CHAPTER II

THE CELLS OF THE BODY

What the cell is.—Most cells are too small to be seen by the naked eye, but the microscope reveals not only the cell, but the minute parts of which it is composed. Fig. 1 represents a cell which may be taken as a type of all cells. On the outside is the cell-wall, which may be thin or thick, circular or irregular in shape, or may be wanting altogether. The cell-wall is not alive, but is the material which has been secreted by the live material within the cell. Within the walls is the cell-substance, or protoplasm. This substance makes up the most of the cell and is found alike in cells of plants and animals. It is a somewhat transparent mass, in some cases a thin liquid, and in others thick like jelly.

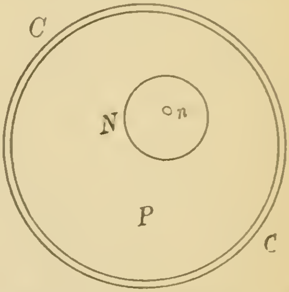

FIG. 1.—Typical cell. *C*, cell-wall; *N*, nucleus; *n*, nucleolus; *P*, protoplasm.

Lying within the protoplasm is the nucleus. This is a small body surrounded by a membrane and having within it several smaller bodies called nucleoli. The nucleus is an essential part of the cell, as will be shown later.

Cellular structures.—All living bodies are made up of cells. Some very small animals consist of only one cell, but all higher animals and plants are composed of many thousands of them. Plant-cells are usually enclosed in heavy walls, and when they are crowded one against another they are forced to assume a shape best suited to the space they occupy, as shown in Fig. 2. In Fig. 3 is shown the arrangement of cells in a twig of basswood as seen through a low-power microscope. The outline of the cell-walls can be plainly seen arranged in rows radiating

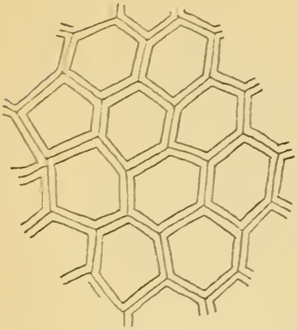

Fig. 2.—Diagram of a collection of plant-cells.

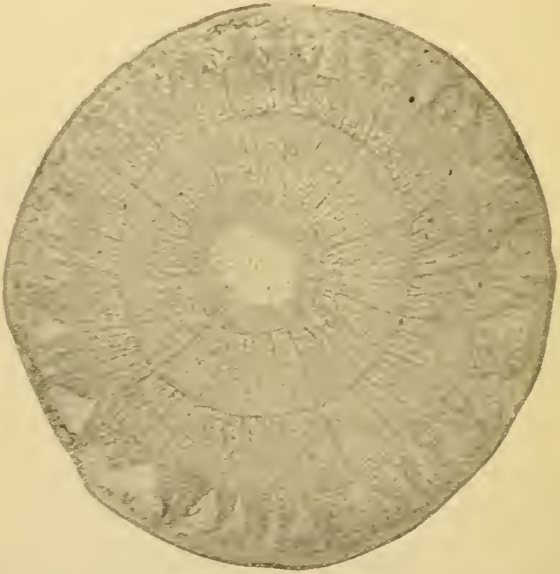

Fig. 3.—Microphotograph of a cross-section of a twig of basswood.

from the centre. Dry wood, in fact, is only a collection of cell-walls. The strength of wood depends on the kind and amount of material deposited in the walls of the cells. Fig. 4 gives the appearance of a cross-section of pinewood.

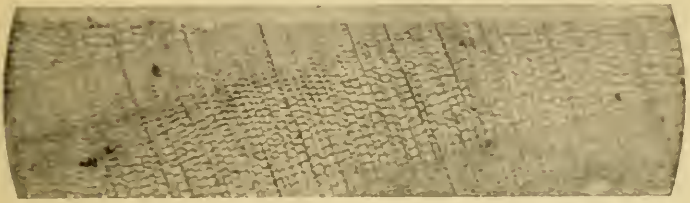

FIG. 4.—Cross-section of pinewood.

In plants as in animals there is a division of work among the cells. Some assume the office of protection of the others. Some collect and prepare the plant food. A great variety of work is performed by the various tissues of which the plant is composed. Fig. 5 shows the microscopic appearance of the surface of a leaf. The large flat cells are plainly seen, but the points of chief interest are the modified cells about the *stomata*, or

FIG. 5.—Surface of leaf showing stomata.

mouths. These are a good example of special functions of cells. Their office is to regulate the transpiration of water from the leaves. When water in the leaves is scant, these cells close the stoma and prevent its escape, but when water is present in excess the cells open the stoma and permit it to freely evaporate.

The cells of plants have many characteristics in common with those of animals, though the latter are often less clearly defined and more difficult to study. In the tissues of animals a distinction should be made between the cell proper and the material which the cells collect about themselves. In Fig. 6 is a representation of three bone-cells highly magnified. The spaces between the cells are filled in with bone material which may be considered the walls of the cells.

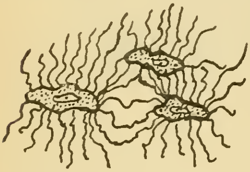

FIG. 6.—Bone-cells.

In the same way the muscle, nerves, cartilage, and other tissues are largely composed of material which the cells have built up about themselves and which may be considered a cell-wall modified to suit the special purpose of the tissue.

The origin of cells.—The body of man, as well as the bodies of all higher animals and plants, begins as a single cell, or egg. The egg, *A*, Fig. 7, divides into halves forming two complete cells. Each of the halves, in turn, divides into two, making four, then eight, sixteen, thirty-two, and so on. Several stages in the division of the egg are illustrated in Fig. 7. The last, *E*, has the appearance of a berry, and is called the mulberry stage of development. This bundle of cells is closely bound together, and continues to grow by a multiplication of cells and an accumulation of cell material. The bodies of man and all higher animals are formed out of such bundles of cells. All start as a single cell, which by dividing and subdividing results in the growth of the body. The body of a full-grown man is composed of many millions of cells.

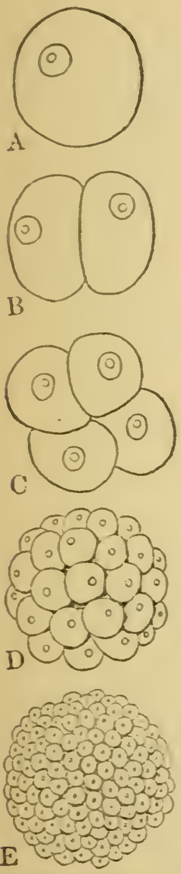

FIG. 7.—Diagram illustrating the multiplication of cells from a single cell.

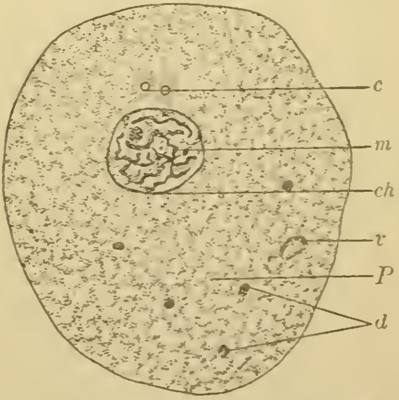

FIG. 8.—Appearance of a cell under a strong microscope.

Parts of a cell.—Microscopes have been very much improved, and scientists have learned much better ways of using them, so that now they can see many things which before escaped their notice. In Fig. 8 is shown a cell as it appears under a modern microscope. The protoplasm, *P*, has the appearance of a mass of foam. Near the centre of the cell is the nucleus surrounded by a membrane, *m*. Within the membrane appear two different kinds of substances. One is like the protoplasm in the body of the cell, and the other is represented in the figure by the heavy lines, *ch*. This latter substance is called *chromatin*, and is one of the most interesting and important parts of the cell. Just above the nucleus appear two aster-like bodies, *c*. These are called *centrosomes*. At first only a very small dot appears, but soon it divides into two, which are later surrounded by the radiating fibres as shown.

The other marks are not essential parts of the cell. An empty space is seen at *v*, and *d* is only a speck of lifeless matter.

The nucleus.—All cells have a nucleus in some form. It is the most essential part of the cell. Without the nucleus a cell cannot assimilate food or reproduce itself. Some interesting experiments have been performed to demonstrate the importance of this part of the cell. Certain small animals are made of only one cell, but are large enough so that they may be cut into parts and the action of the parts observed through a microscope. In Fig. 9 is a representation of such an animal. A bead-like string of nuclei extends through its body. If it be cut into parts as shown at *B*, the two upper pieces will contain nuclei, but the lowest one will not. It would then be observed that the two nucleated pieces live on as though nothing had happened to them, and each in time would take on the same form as the original. The other piece would be observed to move about for a short time, but it would not assimilate food or change its form, and soon its life would cease. Such experiments show that the nucleus is a vital part of the cell.

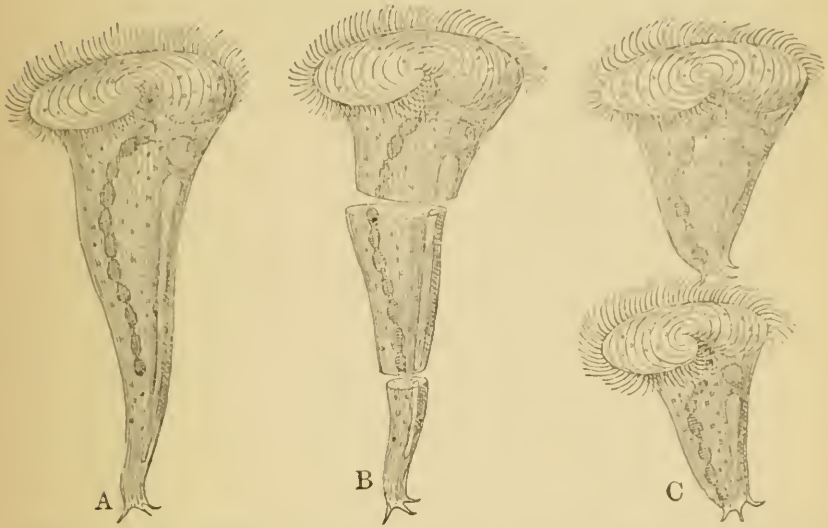

Fig. 9.—*A*, protozoa; *B*, same cut into three parts, the lowest being without nuclei; *C*, the two nucleated pieces regaining the form of the original.

How new cells are formed.—This is a subject of great importance in biology and physiology. We here give the principal steps by which one cell becomes two. The diagrams show only the part of the cell to which attention is particularly directed. A cell at rest is represented in Fig. 10. The nucleus is filled with a net-work of fibres, and just above it are the two dots called *centrosomes.* Sometimes only one dot is seen, but it soon divides into two. These soon begin to change in a very interesting way.

The first change noticed is in the nucleus. Here the fibres form into a thread and then break up into a number of pieces called *chromosomes*. The number of chromosomes is always the same for animals of the same species. In this cell there are four.

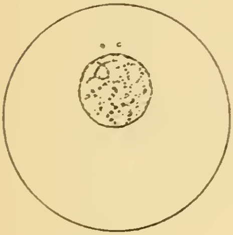

FIG. 10.

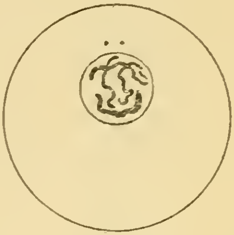

FIG. 11.

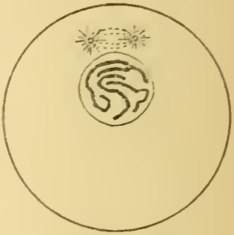

FIG. 12.

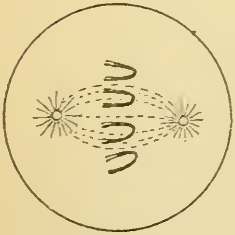

FIG. 13.

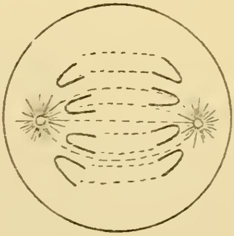

FIG. 14.

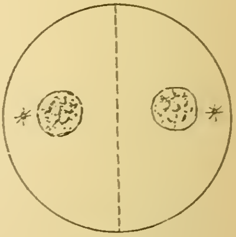

FIG. 15.

The next change is seen in the centrosomes. They assume a star-like appearance and begin to move from each other, as shown in Fig. 12, though they are still connected by fibres running from one to the other.

The membrane about the nucleus now disappears, and the centrosomes continue to separate until one is on each side of the cell with the chromosomes between them, as shown in Fig. 13.

The change which now follows is most wonderful of all. The chromosomes split lengthwise into two equal parts. Four of these, in this particular cell, move to one centrosome and four to the other. The division of the chromosomes into equal parts insures that the new cell will be just like its parent.

The last step in the division is represented in Fig. 15. A partition grows through the body of the cell dividing it into two parts. A membrane surrounds each set of chromosomes, which now become the nuclei of the new cells. A centrosome remains with each nucleus. The cells separate, and each takes up its particular work in the body until again they undertake the process of division just described.

The single cell.—Many very small animals are composed of only one cell. When they divide and become two, each lives independent of the other. The *amœba*, shown in Fig. 16, is such an animal. When at rest it may be spherical in form, and is then only about $\frac{1}{1000}$ of an inch in diameter and looks like a lump of clear jelly. It contains a nucleus, but the parts of its body are all alike. It has no feet, mouth, stomach, or lungs, and yet it moves, eats, digests its food, and breathes. It can put forth a projection from its body on any side and then cause the rest of the body to flow into it. In that way it moves about. It may wrap its body about other very small animals or particles of food, and digest them. In that way its whole body becomes, for a time, a stomach. At any point of its body it takes in oxygen from the air in water and gives out carbon dioxide just as other animals do. Thus it can turn any part of its body to a

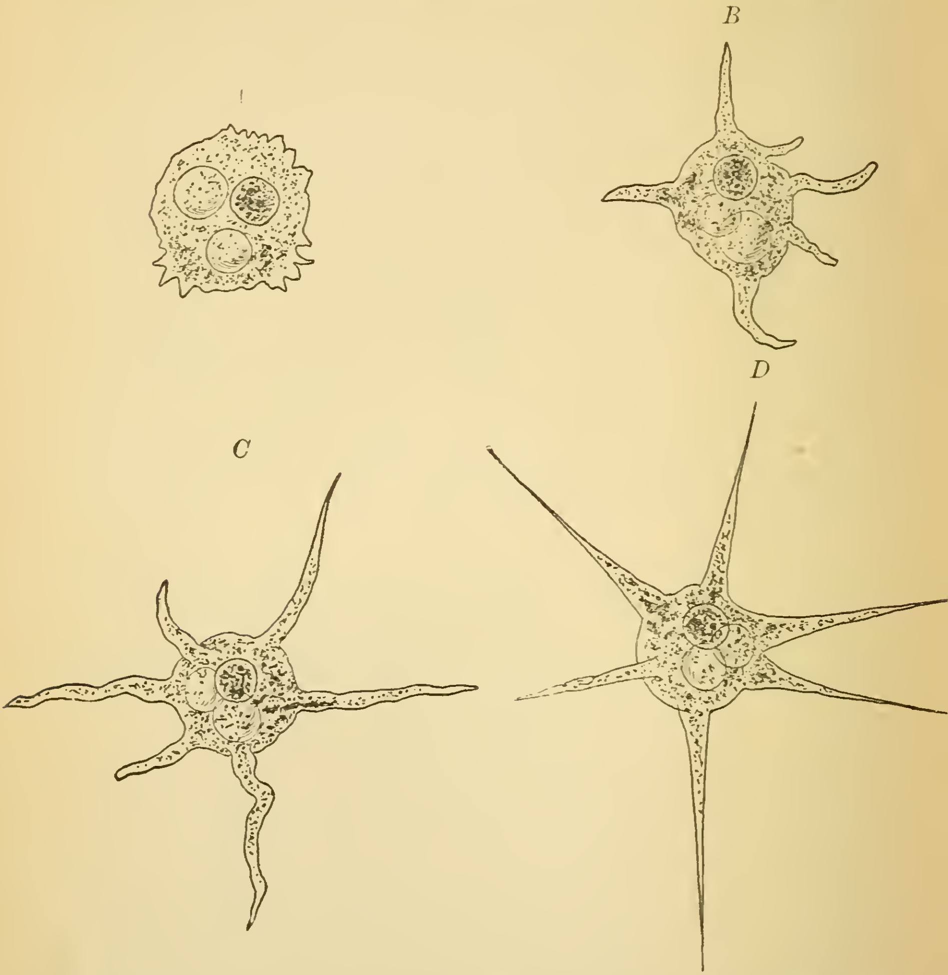

Fig. 16.—The amœba radiosa. *A*, *B*. *C*, and *D* are views of the same amœba, showing how it changed its shape within a few minutes. One of the circles within the body represents the nucleus and the other two are particles of food. The amœba itself is only $\frac{1}{300}$ as large as shown in this cut.

variety of uses, but no one part has any special duty to perform.

A knowledge of the amœba is important in a study of physiology, because a great number of one-celled structures of this kind are found within the human body. They are called *white corpuscles*, and are of the greatest service to the body, as will later be shown.

A collection of cells.—It is plain that an animal of only one cell can never grow very large or accomplish very much alone. In all higher animals, including man, a great number of cells are joined together forming one body, and the work of the body is divided among them. Some cells are concerned only in building up a bony framework for the body; some secrete fluids needed for the digestion of food; some form the protecting layer on the outside of the body. Just as in a large factory there is a division of labor, and each workman is an expert in some particular process or operation, so there is a division of labor among the cells of the body. Thus each cell becomes specially fitted for doing some particular thing necessary to the welfare of the whole body.

Tissue.—A number of cells of similar origin grouped together and having a special work to do in any part of the body constitute a *tissue*.

Each cell is alive and to some extent is independent of the other cells, but, as already shown, a single cell is so small that it is a very helpless creature when alone. We have to use a good microscope to even see it. A single cell of muscle can contract, but its effort is very feeble. When, however, thousands of them act together, the bundle of muscle is able to lift heavy weights and perform hard labor.

There are in the body six different kinds of tissue: (1) Epithelium; (2) Connective; (3) Adipose; (4) Osseous; (5) Muscular; (6) Nervous.

Epithelium.—*Epithelium* is the name of the layers of cells that cover the whole outside of the body and line all the vessels within that communicate with the outside.

Epithelium is a very common and a very important tissue.

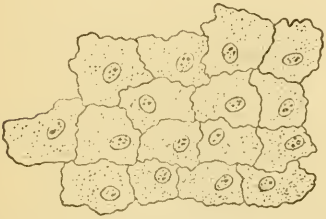

FIG. 17.—Pavement epithelium.

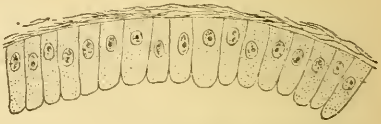

FIG. 18.—Columnar epithelium.

Its chief use on the surface of the skin is to protect the parts beneath it. Here the cells are flat, and are fitted together at their edges much like the tile in a pavement, and so it is called *pavement epithelium*, Fig. 17. The nails and hair, also the claws and horns of animals, are made of this kind of tissue.

Another kind is called *columnar epithelium*, for, as seen in Fig. 18, the cells are set on end and have the appearance of columns. This kind of cells lines the stomach and intestines.

Still another kind, shown in Fig. 19, is called *ciliated epithelium* because the cells have projections at the top that look like eyelashes (cilia). While the cells are alive the cilia are in constant motion, lashing back and forth.

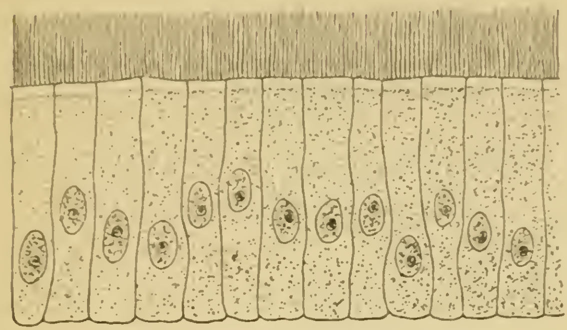

FIG. 19.—Ciliated epithelium.

Such cells line the air-passage of the nose, windpipe, and lungs. They are also found in various other parts of the body.

Connective tissue.—Connective tissue is distributed throughout the body, and its duty is to bind together and support the various parts.

One kind is called *white fibrous tissue.* It forms the ligaments which bind the bones together at the joints. It is the tissue of the tendons that connect muscle to bone. It serves as a tough membrane to cover various organs of the body. In nearly every organ of the body it is an indispensable connecting tissue. When seen under the microscope it has the appearance of silvery white waving bands. It is not elastic, but is very strong. Even the bone to which it is attached will break before the white tissue will give way.

An example of its strength may be seen in a butcher-shop where a beef or pork is hung from a peg by the tendon of the hind leg.

Another kind of connective tissue is called the *yellow elastic tissue.* It differs from the white fibrous tissue in color and also in the fact that it is elastic. It can be stretched, and will return to its original condition as soon as the stretching force is removed. It is found in various places in the body where such a tissue is needed, as in the skin, vocal cords, and arteries.

A third kind is called *areolar tissue* because its fibres are lax and the spaces between them may be easily filled up with air or a liquid. This tissue is very abundant in the body. It binds parts together, but allows them to move freely on each other. It is found, for example, just under the skin, all over the body. It is this tissue which allows the skin to have such great freedom of movement. When the hide is removed from a dead ox it is only the areolar tissue that needs to be severed.

Adipose tissue.—Adipose tissue is a collection of cells that contain fat. Each cell has a nucleus and is alive like other cells, but is degenerate and soon to die. This tissue is found in many parts of the body within the areolar tissue. It is often abundant beneath the skin and around the heart and kidneys. The fat of the cell is a liquid while the animal is alive but becomes solid after death. Lard is obtained from the adipose tissue of the hog, and tallow from that of beef.

Fat is also found in the body outside of adipose tissue. It is not part of a cell, but consists of little globules of fat such as are found in the blood. The use of fat will be described under the subject of food.

Osseous tissue.—*Osseous tissue* is the name applied to the collection of cells that build up the bone of the body. Three such cells are shown in Fig. 6. Their function is to gather from the blood the material they need, and to build up around themselves the hard and strong substance called bone. Bone is made hard by the lime compounds—calcium phosphate and calcium carbonate—which the cells secrete.

In some parts of the body these cells do not secrete lime, and then the tissue is called *cartilage*. Such is the nature of the pads between bones at the joints, and many other parts of the body. If the cartilage of the external ear were as inflexible as bone, there would be great danger that it might be broken off by accident. Cartilage, however, is classed with the osseous tissue.

Muscular tissue.—*Muscular tissue* is the name of a very abundant collection of cells which form a material called muscle. This tissue can contract under the influence of the cell. It thus pulls upon the bodies to which its ends are attached and draws the bodies closer together. This tissue is used in every motion that is made by the body.

Nervous tissue.—*Nervous tissue* is a collection of cells that form the brain, the spinal cord, the nerves, and the ganglia. These cells are provided with long thread-like projections that run out to the cells of other tissues. In this way the nerve-cells have a directing and controlling influence over all parts of the body.

Organs.—A collection of cells having similar work to perform is called a tissue.

A collection of several kinds of tissue all working to the same purpose is called an *organ*. The ear, for example, is made up of many different tissues, which together form the organ of hearing. The lungs are the organs of respiration. The stomach, intestines, liver, and pancreas are organs of digestion. The eye is the organ of sight, and the brain of thought.

Systems.—A *system* includes several organs working together to the same end. The circulatory system would include all organs that have to do with the circulation of blood or other fluids. These would be the heart, arteries, capillaries, veins, and lymphatics.

Six important *systems* may be named : *digestive, circulatory, respiratory, nervous, excretory,* and *motor.*

The excretory system includes all those organs that are concerned in getting rid of the waste products or other substances that would be injurious if retained in the body.

The motor system includes the muscles, bones, tendons, and motor nerves as far as they are concerned in giving to the body its variety of motions.

Many organs belong to two or more systems. The lungs, for example, are organs of respiration, but in expiration they are also organs of excretion, since carbon dioxide and other waste matter thus escape into the air.

Glands.—In many places in the body it is necessary to *secrete* from the blood certain liquids which are needed in the economy of the body. Examples of such secretions are the juices needed to digest food, and the sweat which is poured out on the skin.

At other places it is necessary to *excrete* matter for which the body no longer has any need, or matter which would be harmful if not promptly thrown off. An example of this is the urea which is excreted by the kidneys.

Secretion and excretion are accomplished by organs called *glands*. A simple form of gland is represented in Fig. 20. It consists of a layer of epithelial cells built up in connective tissue around a cavity and having an outlet called a *duct*. A net-work of blood capillaries lies close to these cells on the outside. The cells take from the blood the material suited to the special purpose of the gland. For example, the glands of the mouth will secrete saliva and those in the stomach will secrete gastric juice.

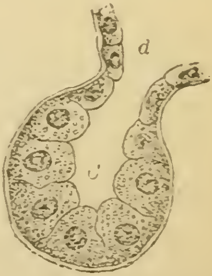

FIG. 20.—Type of gland. *C*, cavity surrounded with epithelial cells; *d*, duct.

Serous and mucous membranes.—The two principal lining membranes of the cavities of the body are the *serous* and *mucous* membranes. The *serous mem-*

brane lines all cavities that are closed, that is, having no communication with the outside of the body. This membrane lines the cavities of the abdomen, and is there called the *peritoneum*; it covers the lungs, and is there called the *pleura*; it surrounds the heart, and is there known as the *pericardium*.

Serous membrane is thin and glistening and always moist in a healthy body. It is a protection and support to the body it surrounds.

The *mucous membrane* lines all cavities that communicate with the outside.

It may be considered as a continuation of the skin which covers the outer surface of the body. It is composed of layers of epithelial cells, and contains, in many places, small glands which secrete fluids suited to the purpose of the organ which they line.

The two cavities of the trunk.—The trunk of the body is divided into two main cavities. The upper one is called the *thorax* and the lower one the *abdomen*. They are separated by the *diaphragm*, which is a partition between them. The lungs, heart, and large blood-vessels are the principal organs in the thorax.

In the abdomen are the stomach, small and large intestines, liver, kidneys, spleen, pancreas, and numerous blood-vessels.

QUESTIONS FOR REVIEW.

1. What are four parts of a typical cell?

2. What is protoplasm? (Consult also the dictionary and cyclopaedia.)

3. What is wood?

4. What are stomata, and how do they operate?

5. What distinction is made between the cell and the cell material?

6. Make a drawing of several bone-cells.

7. How do cells originate?

8. What is the unit in the animal body?

9. Make a drawing to illustrate the appearance of a cell under a strong microscope.

10. Describe the several parts that may be seen.

11. Describe an experiment showing the importance of the nucleus.

12. Describe six steps in the formation of new cells from old ones.

13. What is karyokinesis? (See dictionary.)

14. What part of the process makes it almost certain that the new cells will be like the old?

15. Describe the amœba.

16. How is it different from other animals?

17. What cells of similar kind are in the body?

18. What is meant by a division of labor?

19. What is the advantage of a collection of cells?

20. What is a tissue?

21. How many kinds of tissue in the body? Name them.

22. Define epithelium.

23. Describe and make drawings of three different kinds of epithelium.

24. Why should there be different kinds?

25. What is the function of connective tissue?

26. Describe and give examples of three kinds of connective tissue.

27. Describe adipose tissue.

28. What is osseous tissue?

29. What is the function of muscular tissue?

30. What is the relation between the nervous tissue and the other tissues?

31. What is an organ? Give examples.

32. What is a system? Name six.

33. Define the duty of each system.

34. What is secretion and excretion?

35. Describe the structure of a simple gland.

36. Of what use are glands?

37. What is serous membrane, and where is it found in the body?

38. What kind of organs are lined with mucous membrane?

39. What kind of fluids do glands secrete?

40. What are the two main cavities in the trunk of the body, and what are the chief organs in each?

CHAPTER III

THE SKELETON

THE skeleton of the human body is made of bones, with pads of cartilage at the joints and strong ligaments holding the joints in place.

Use of bones.—Bones are of great use to the body in four different ways. (1) They determine the general figure and shape of the body. (2) They protect the delicate and vital parts. (3) They furnish support for the softer parts. (4) Many of them can be used as levers, so that the muscles can give to the various parts of the body the kind of motion best suited to our needs.

Number and names of bones.—In the adult human body there are two hundred and six different bones, with thirty-nine different names.

(The common names of bones are in constant use, and are a part of the vocabulary of every intelligent person. For this reason the student is urged to make himself familiar with the names given below.

Another reason for committing these terms and others that follow is that any science can be clearly understood only when the terms in which it is expressed are clearly defined in the mind of the reader. The student is expected not only to give the names, but to locate the

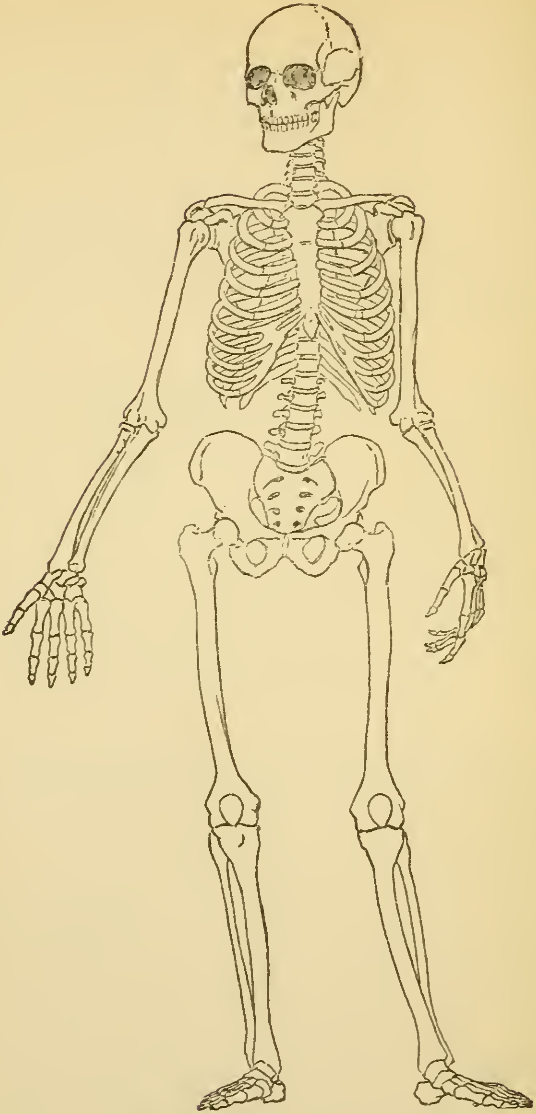

FIG. 21.—The human skeleton.

After a study of the following pages on the skeleton, the student will be expected to rapidly name all the parts here shown without reference to other pages.

bones either by reference to his own body or by reference to the cut on the opposite page or on a physiological chart.)

BONES OF THE HUMAN SKELETON.

The skull—8 bones . .	1 *Frontal*, forehead.
	2 *Temporal*, temples.
	2 *Parietal*, sides of head.
	1 *Occipital*, back of head.
	1 *Sphenoid*, base of skull.
	1 *Ethmoid*, front of skull.
The face—14 bones . .	2 *Nasal bones*, bridge of nose.
	2 *Malar bones*, cheek.
	2 *Lachrymal bones*, at inner part of the orbit of the eye.
	2 *Turbinated bones*, in nostrils.
	1 *Vomer*, between nostrils.
	2 *Palate bones*, in back part of roof of mouth.
	2 *Upper maxillary*, upper jaw.
	1 *Lower maxillary*, lower jaw.
The ear—6 bones . .	2 *Malleus*, the hammer.
	2 *Incus*, the anvil.
	2 *Stapes*, the stirrup.
The vertebral column —26 bones	7 *Cervical vertebræ*, in neck.
	12 *Dorsal vertebræ*, in back.
	5 *Lumbar vertebræ*, in small of back.
	1 *Sacrum*, at lower end of vertebral column.
	1 *Coccyx*, below sacrum.
The *ribs*—24 bones . . .	12 ribs on each side of thorax.
The *sternum*—1 bone . .	breast-bone.
The *os innominatum*— 2 bones	the hip-bones.

The *hyoid*—1 bone . .	at base of tongue.
The upper limbs—64 bones	2 *Clavicle*, collar-bone, at top of chest, in front.
	2 *Scapula*, shoulder-blade, back of shoulder.
	2 *Humerus*, arm.
	2 *Radius*, forearm, on same side as the thumb.
	2 *Ulna*, forearm, by the side of the radius.
	16 *Carpal bones*, wrist-bones.
	10 *Metacarpal bones*, in body of hand.
	28 *Phalanges*, 3 in each finger and 2 in each thumb.
The lower limbs—60 bones	2 *Femur*, thigh-bone from hip to knee.
	2 *Patella*, knee-pan.
	2 *Tibia*, shin-bone.
	2 *Fibula*, by shin-bone on outer side.
	14 *Tarsal bones*, ankle-bones.
	10 *Metatarsal bones*, in the body of foot.
	28 *Phalanges*, 3 in each toe and 2 in each great toe.

Classes of bones. Long bones.—As to their structure and use, bones may be classified as *long*, *short*, *flat*, and *irregular*. The *long bones* are the humerus, radius, ulna, femur, tibia, fibula, metatarsal and metacarpal bones, the phalanges, and the clavicle.

Long bones are not always of great length. The bones of the fingers are short, and yet they are classed with the long bones. A long bone may be described as a hollow cylinder, having thick and very compact bony tissue at its middle but expanded at its extremities, where the bone is of a spongy character. Fig. 22 shows part of a long bone that has been cut in two lengthwise.

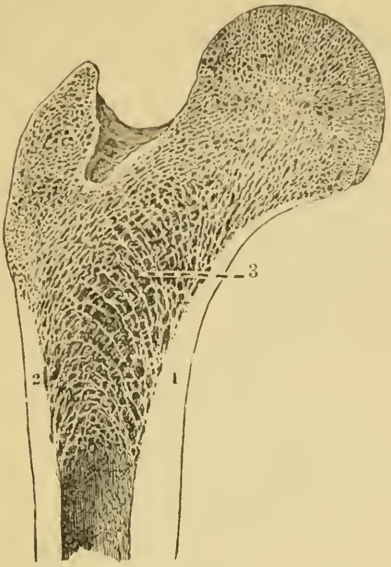

FIG. 22.—Longitudinal section of upper end of femur. 1, 2, compact bone; 3, cancellated bone.

Short bones.—The *short bones* are such as those of the carpus and tarsus. They are made of spongy bone, and covered with a thin crust of hard, compact bone.

Flat bones.—The *flat bones* are used to protect other parts of the body and to furnish a broad surface for the attachment of muscle. They are made of two plates of hard bone, quite close together, with spongy bone between.

The flat bones are the frontal, parietal, occipital, nasal, lachrymal, vomer, scapula, hip-bones, sternum, ribs, and patella.

Irregular bones.—The *irregular* bones are so called because of their form. They are all bones of the skeleton not included in the other three classes. They all have a hard, bony shell on the outside with spongy bone tissue within.

The cranium.—The *cranium* is a strong bony box which supports and protects the most delicate and most important organ of the body,—the brain. In the cranium of the adult, as shown in Fig. 23, the flat bones are joined edge to edge by a kind of joint called a *suture.* The edges grow into each other and form a solid union. The cranium of the infant is soft and easily distorted, because the bones are not yet hardened with lime.

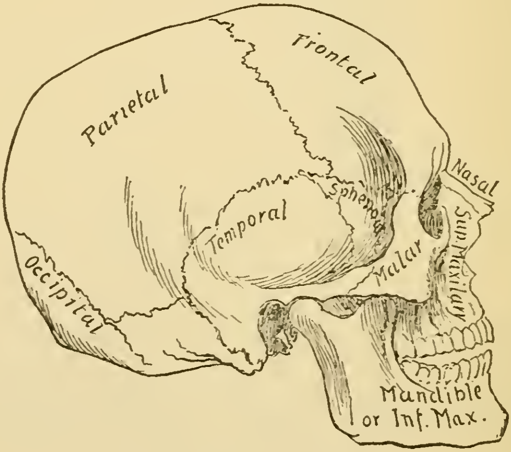
Frontal
Parietal
Nasal
Sphenoid
Temporal
Sup. Maxilary
Malar
Occipital
Mandible
or Inf. Max.

Fig. 23.—Cranium.

All the other bones of the skull articulate with the sphenoid, which, like a wedge, holds them firmly together.

The vertebral column.—The *vertebral column* is composed of 33 vertebræ (Latin, *vertere*, to turn) placed one on top of the other. The characteristic parts of a vertebra are the body, several processes, and a perforation just back of the body. These are shown in Fig. 24.

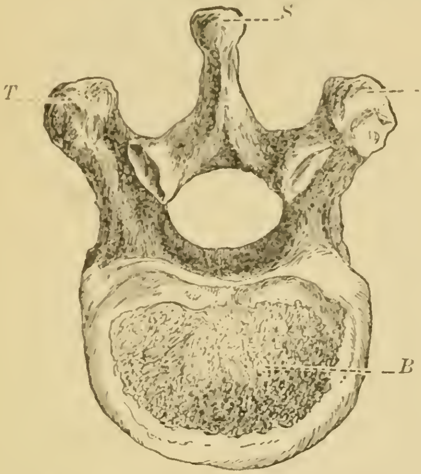

FIG. 24.—Vertebra. *B*, body; *T*, transverse process; *S*, spinous process.

The vertebræ are piled up in the manner shown in Fig. 28, and serve as a strong pillar to hold up the head and the trunk of the body. The holes together form a tube for the protection of the spinal cord.

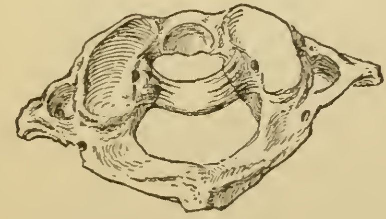

FIG. 25.—Atlas.

The atlas.—The topmost vertebra is called the *atlas*, because the head rests upon it (see Atlas in dictionary).

It differs in shape from the other vertebræ, as may be seen in Fig. 25. It articulates with the base of the skull, and when the head is turned it turns with it.

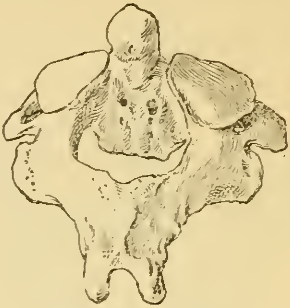

FIG. 26.—Axis.

Axis.—The second vertebra is called the *axis*, because it forms a pivot upon which the atlas rotates. The peculiarity in the shape of the axis is the tooth-like projection called the *odontoid process*. The atlas fits over this process and rotates about it when the head is turned from side to side.

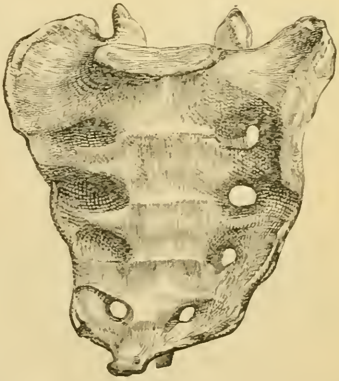

FIG. 27.—Sacrum and coccyx.

Sacrum and coccyx.—At the lowest point of the backbone is the *coccyx*. In early life it consists of four separate bones, but later they grow together and form one solid bone. It is called the coccyx because it looks like the beak of a cuckoo.

Just above the coccyx is the sacrum, or sacred bone. It is so called because it was once used in sacrifices. In early life it is composed of five separate bones, but later they grow together.

The sacrum and coccyx, together with the two large hip-bones, form a strong basin at the base of the trunk of the body. It is called the *pelvis*, because *pelvis* in the Latin language means basin (see skeleton on page 34).

Flexibility of the backbone.—The body of each vertebra is about one inch thick. When they are placed one on top of the other they form a column that is slightly curved like the letter S. The bony part of the vertebræ do not touch each other. There is a pad of elastic cartilage between them, and all are bound firmly together by strong ligaments.

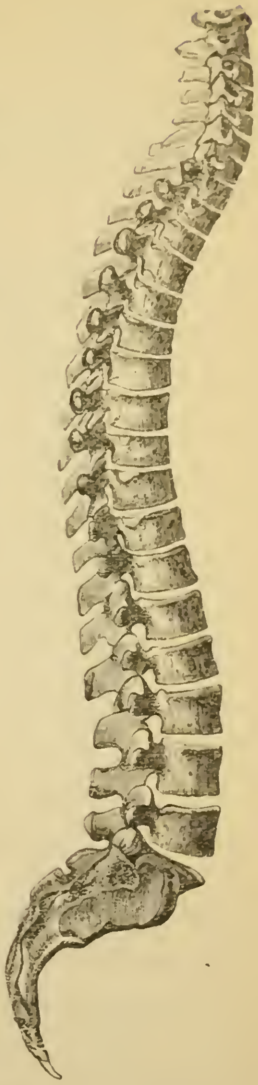

Fig. 28.—Showing curves of spinal column.

Both the shape of the column and the pads of cartilage prevent sudden jars from walking, jumping, or a slight fall. The cartilage also permits great freedom of movement in all directions.

The ribs.—The ribs are flat. elastic bones surrounding the chest. They are twenty-four in number, twelve on each side. The upper seven on each side are *true ribs.* and the lower five are *false ribs.* All articulate with the backbone by a true joint. two to each dorsal vertebra. In the front the seven true ribs are joined to the sternum by means of cartilage. The first three false ribs are joined in front to the cartilage of the lowest true rib. and the two remaining ones have no attachment in front, and so are called *floating ribs.* The

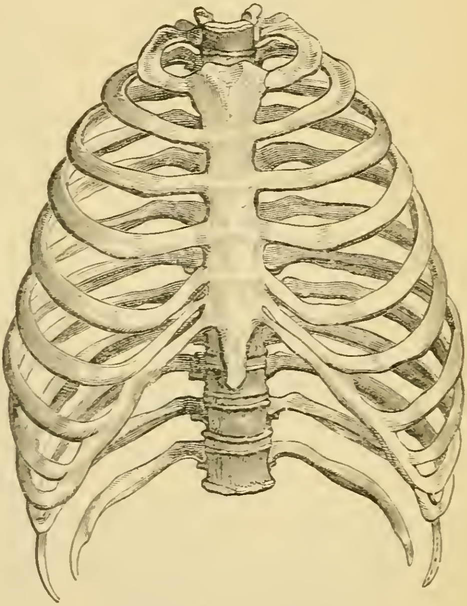

FIG. 29.—The ribs.

ribs do not pass straight around the chest, but are lower in front, and also sag in the middle. The advantage of this will be apparent when we come to the study of breathing.

The extremities.—There are many points of similarity between the bones of the arms and legs. The femur is the largest bone in the body, and the corresponding bone in the arm is the humerus. The tibia is the next longest, and is on the same side as the great toe. The radius of the arm is a corresponding bone on the same side as the thumb. The fibula of the leg has its

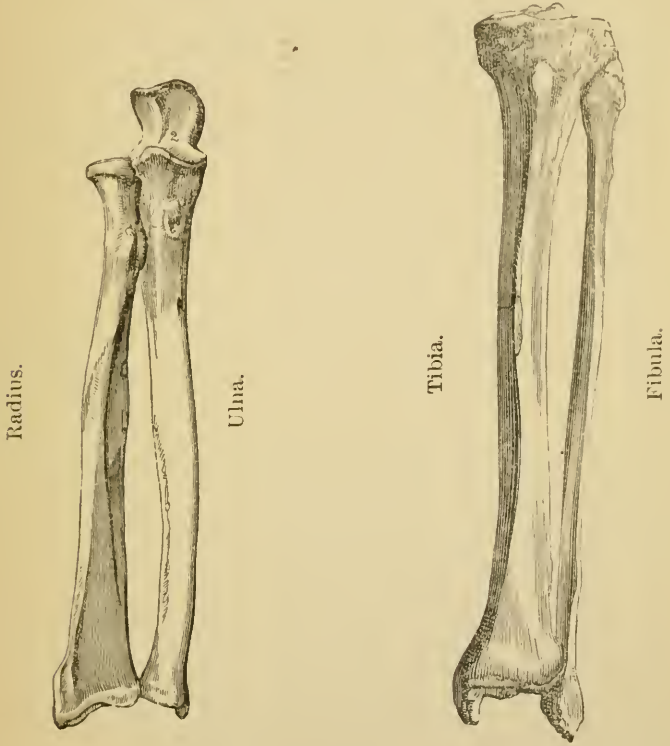

FIG. 30.— Forearm and lower leg.

counterpart in the ulna of the arm. The tarsus is similar to the carpus. The metatarsus and metacarpus are much alike, and both the feet and the hands end in phalanges.

QUESTIONS FOR REVIEW.

1. Give four uses for bones.
2. How many bones in the human body?
3. Give good reasons for learning their names.
4. Name and locate the bones of the skull.
5. Point out and name the bones of the face.
6. Define the names of the ear bones.
7. What are the three classes of vertebræ? Locate them.
8. What are the three kinds of ribs?
9. Where is the sternum? The os innominatum? The hyoid?
10. Name all bones of the upper limbs.
11. Name all bones of the lower limbs.
12. Name together the corresponding bones of the arms and legs.
13. Point out on the chart all the bones of the body, giving names.
14. How are bones classified as to their structure?
15. Define a *long bone*. Name all the long bones.
16. What is the structure of *short bones?* Of *flat bones?*
17. To which of the four classes do the ribs belong?
18. Locate the sphenoid.
19. How many vertebræ are there, and why are they so called?
20. Which vertebra is called the atlas? Why so called?
21. What is the use of the odontoid process?
22. What is the *pelvis?*
23. What provision is made to relieve the brain from sudden jars?
24. What is the difference between the *true*, the *false*, and the *floating* ribs?
25. How can you tell which of the two bones in the forearm is the radius?

CHAPTER IV

STRUCTURE AND NOURISHMENT OF BONE

Strength of bones.—Bones which are to serve as a framework of the bodies of animals should be strong and at the same time light. This condition is brought about by making all long bones in the form of tubes, as shown in Fig. 22. A tube will support much more weight than the same amount of material in form of a solid rod. This principle is utilized in the use of hollow iron pillars for the support of buildings and in the hollow stalks of grasses and grains. In the middle of the shaft of the long bone the tube is smaller, but the walls are thicker and almost as compact as ivory. Towards the ends the walls are thinner and the shaft larger. The expanded ends are filled with spongy bone which looks something like lattice work, and so is called *cancellous bony tissue.* The strength and lightness of flat bones are secured by having two plates of compact bone with cancellous tissue between them. The shape and structure of a bone depend upon the nature of its service to the body.

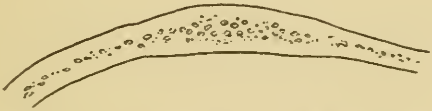

FIG. 31.—Cross-section of a flat bone.

Microscopical examination of bone.—When we look through the microscope at a very thin slice of bone it is seen to have a very definite and interesting structure which can never be seen with the naked eye. Fig. 32 illustrates the appearance of such a cross-section.

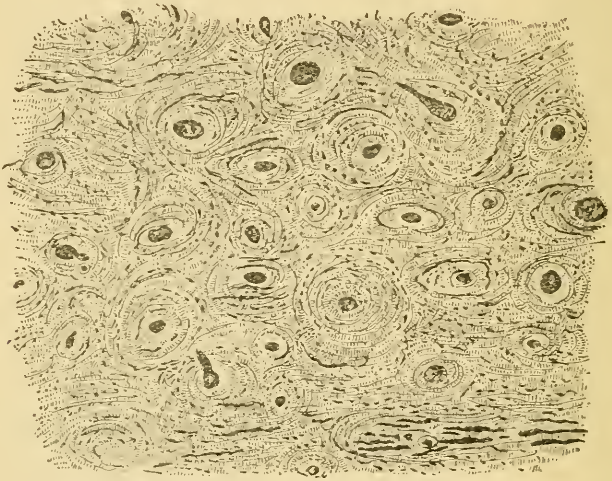

Fig. 32.—Cross-section of bone, highly magnified.

The holes at the centres of the circles are only about $\frac{1}{500}$ of an inch across, some being larger and some smaller. These holes are tubes cut across. The tubes run lengthwise with the bone and are called *Haversian canals*, from the name of the discoverer, Dr. Havers. The bone-cells are arranged in circles around the canals. Their location may be determined by the black, irregular spots called *lacunæ* where the living cell resides. Very fine tubes, called *canaliculi*, radiate from each lacunæ, connecting them one to another and with the central Haversian canal. Each canal with its concentric layers of lacunæ and canaliculi form a *Haversian system*. Highly magnified bone-cells are represented in Fig. 6.

How bone is nourished.—The bone-cells, like most cells of the body, are fixed to one place. Their food must be brought to them or they will starve. The bones that are usually picked up for examination are dead bones. They are no more like the live bone than a dead twig on the ground is like a live one on a tree. When a live bone is cut, blood will ooze from its numerous canals. It is plain that the blood here, as elsewhere, is the agent by which food is brought to the cells. All bones are surrounded by a membrane called the *periosteum* (around the bone). In this membrane are numerous blood-vessels that enter the bone in many places and traverse the Haversian canals. The hollow bones are lined on the inside with a similar membrane called the *endosteum*. An artery enters the long bone usually through a foramen at about the middle of the shaft. It distributes itself in the endosteum. From this source the marrow which fills the hollow of the bone receives its nourishment, and also the inner layers of bone are supplied with bone material from the same source.

Composition of bone.—A chemical examination shows that bone is composed of two kinds of substances closely mixed together. One of these is called *animal matter* and the other *earthy matter*,—about one-third of the former and two-thirds of the latter. The earthy matter may easily be removed from bone by submersion for a time in dilute muriatic acid. (See directions at end of this chapter.) The acid readily combines with the lime compounds, so that in the course of a day only the animal matter of bone remains in place. This is now so flexible that it may be tied into a knot, as shown in Fig. 33.

A piece of fresh bone put into a hot fire for an hour or two will lose all its animal matter, and only the hard part, which is largely the phosphate and carbonate of lime, will remain unburned.

The bones of young children are quite soft. because they are composed of a large proportion of animal matter.

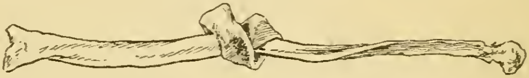

FIG. 33.—Bone tied in knot.

As the child grows older. more and more lime is deposited about the cells, and so the bones grow harder and more brittle. Ossification begins at the middle of a bone and extends out to the joints.

The shafts of the long bones are filled with a yellowish fatty substance called *marrow.* The cancellous tissue is filled in with a thin reddish liquid, which is sometimes called marrow, though it contains very little fat, while true marrow contains 96 per cent. fat.

This red liquid is intimately connected with the formation of new red blood-corpuscles.

Health of bone.—Bone has but few nerves distributed to it. and so we feel but little pain from any wound which it receives. It may become diseased, however, just like any other part of the body. Good bone can be built up by the cells only when the necessary material is furnished to them in the blood. Bone is formed from the materials in the food which we eat.

There is a disease called *rickets*, which is common with children who live on scant and poor food. The backbone and legs are often bent and distorted, because the bone-cells are poorly fed and do not build up a sufficiently rigid tissue.

A man does not reach his full height until about the age of twenty-five years; and, although the bones may have been perfectly healthy, yet they have been soft and flexible. The hardening of bone continues even long after full growth has been attained. The bones of children may be made to take on a variety of shapes and positions which, if allowed to remain so, will become fixed in later life.

Bow-legs are quite a common misfortune, but in most cases the deformity could have been prevented by proper care in the early life of the child, or by proper appliances while the bone was still soft.

Stooping shoulders and a contracted chest are a result of careless habits of posture while the bones are soft. The fault cannot be corrected in later life. The head should be carried erect (not thrown back), the chest expanded forward, and the proper curve of the backbone maintained.

Tight shoes deform the bones of the feet, produce an awkward and unsteady gait, and make walking a painful exercise.

A firm and graceful walk is much more to be admired than a small shoe.

Tight clothing about the waist is sure to deform and displace the lower ribs. The vital organs within the chest and abdomen are seriously hindered in their work by such compression.

Those who sit long in one place should be careful of their posture. School seats should be of such a height that the feet of the pupils may rest squarely on the floor.

Older pupils should have desks of such size that they are never forced into a cramped position. All desks should be close enough together to permit pupils to sit up while they write or do other desk work.

Fracture of bone.—A broken bone is said to be *fractured;* (1) when it is a clean break it is called a *simple fracture;* (2) when the soft parts about a break are lacerated, so that there is an opening from the skin into the bone, it is called a *compound fracture.*

It is a wise provision of nature that the bones of the young are soft and flexible; otherwise, the numerous bumps and falls to which a child is liable would be accompanied by serious results. As the child grows older he becomes more skilful in his movements, and learns how to avoid accidents. The bones become harder and stronger, but also more liable to fracture.

When bone is broken nature sets about at once to heal the fracture. At first a watery fluid is poured out around the broken ends, and this in course of a few days will become thick like jelly. In this a deposit of lime is made until it is almost as hard as bone itself. Thus a natural splint is formed about the fracture, and the ends of the bones are held more firmly in place. It requires five or six weeks for healthy bone to unite, and several months may elapse before union is complete.

It sometimes happens that bones will not readily unite. This is called *delayed union.* The delay may be for months, or may even be permanent.

If the parts of a broken bone *remain in their proper place*, and are *kept quiet* for five or six weeks, nature alone will repair the fracture in a very satisfactory manner. In nearly all cases, however, a broken bone is also displaced, and in that position will not unite at all, or, if it does, will be weak and crooked.

For these reasons the services of a surgeon should always be secured at once.

QUESTIONS FOR REVIEW.

1. How are bones made both strong and light?
2. How is this principle utilized in nature and architecture?
3. What determines the shape and character of a bone? Give examples.
4. What is a Haversian canal? How large are they? What is their use?
5. What are *lacunæ*, and how are they connected?
6. Where are the bone-cells?
7. What constitutes a Haversian system?
8. How do bone-cells get their food?
9. What is the *periosteum?* The *endosteum?*
10. What is inside the long bones?

11. What is the composition of bone?

12. What kind of substance fills the spaces of the cancellous tissue?

13. What is the cause of rickets?

14. Why should young people be careful of their posture in sitting and walking?

15. What is the proper posture?

16. What deformities are caused by tight clothing?

17. What is a *simple fracture?* A *compound fracture?*

18. How are flexible bones an advantage to children?

19. How does nature try to repair a fracture?

20. Why is a surgeon needed when a bone is broken?

21. Why is a horse usually shot when one of his legs is broken?

EXPERIMENTS.

Animal matter in bone.—Secure from the butcher a clean fresh rib of a lamb or sheep. Place it in a bottle or dish of such shape that the bone may be completely covered with about one pint of water. Pour into the water about three ounces of hydrochloric acid and set it aside for twelve hours or more. The acid will dissolve the lime, leaving only the animal matter, which is now so soft and pliable it can be tied into a knot.

Earthy matter in bone.—Place a piece of fresh bone in the hot coals of a stove or furnace for two or three hours. The animal matter will all burn away, leaving only the mineral matter, which may now be broken with a hammer.

Weigh the bone before and after burning. The difference in weight is the weight of the animal matter burned away.

Examination of a bone.—Secure a fresh bone of the lower leg of a sheep or beef and make the following observations:

1. The smooth cartilage at the ends.
2. Try the strength of it.
3. Peel off some of the periosteum.
4. Look for an opening in the side of the bone.
5. Saw the bone in two lengthwise and note the thickness of the bony walls.
6. Examine the marrow.
7. Look for cancellous tissue.
8. Find the endosteum.
9. Secure any bone that is not a *long bone*, saw it in two, and closely examine,

CHAPTER V

JOINTS

Use of joints.—A stone pillar which has been chiselled into the likeness of a man has no need of joints, for it will not need to change its position.

A tree needs no joints, for it is by nature stationary. Joints would be a source of weakness to a tree.

Man and all the higher animals, however, must be capable of a great variety of motions and movements, and for that purpose they are supplied with numerous joints. When a man loses the use of a single important joint he is at a disadvantage in the activities of the world, and is considered a cripple.

The structure of joints.—In all joints of the body where one bone glides on another, three important provisions are made. (1) The surfaces are made smooth. (2) A lubricating fluid is supplied as needed. (3) The bones are bound firmly in place.

These are just the conditions we try to secure in the machines which we build, wherever one part must bear upon another while in motion, and where friction is to be avoided.

Articular cartilage.—The smooth surface of joints is secured by a layer of cartilage on the articulating ends of bones. This is the only part of a bone that is not covered with periosteum.

The smoothness of the cartilage affords ease of movement and its elasticity helps to break the force of any concussion. The cartilage varies greatly in thickness, being thickest at points where the greatest pressure is received,—the middle of the convex surfaces and the edges of concave surfaces.

Synovia.—The joint, however, would soon become stiff or could be moved only with great difficulty without a lubricating fluid ready at any time it is needed. Such a fluid is supplied to all the movable joints. It is called the *synovial fluid* because of its likeness to the white of an egg (see the word in the dictionary). The fluid is secreted by the synovial membrane and poured out on the joint.

How joints are held in place.—The ends of bones at a joint must be held to their proper places, and at the same time there must be freedom of movement. These conditions are secured in a variety of ways. Strong ligaments consisting mainly of bundles of white fibrous tissue (see page 25) are fastened to the bones above and below the joint. The hip-joint, for example, is enclosed by a set of ligaments which form a capsule or box about the joint. Such ligaments are very strong, and will resist even violent attempts to pull the joint apart.

Air-pressure also helps to keep some of our joints in place. This is particularly true of such joints as that in the hip, where the ball of the femur fits into the deep socket of the hip-bone. Any attempt to pull the ball from its socket would be resisted by the pressure of the air because of the vacuum produced in the socket. Since the diameter of the socket is nearly two inches, the air-pressure which would resist any attempt to suddenly pull the bones apart would be about fifty pounds.

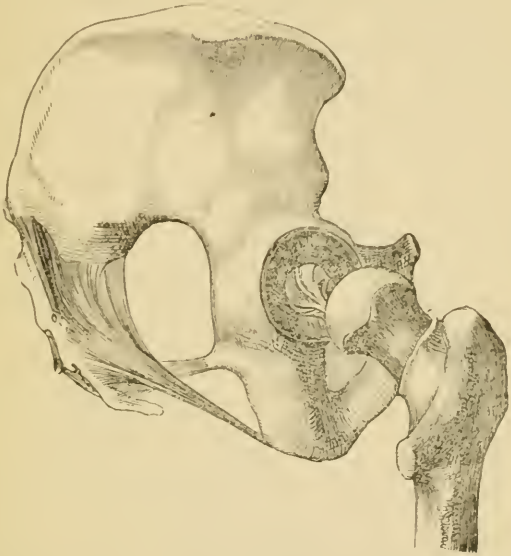

FIG. 34.—The hip-joint. Capsular ligaments stripped back to show the ball and socket.

Kinds of joints.—Nature tries to make each organ of the body most efficient in its particular kind of work. We would expect to find that the joints in the various parts of the body would be of a kind best suited to the work which that part of the body has to do. Joints may be classified as *immovable* and *movable*, the latter being of greatest interest and importance.

The immovable joints are those where the bones are almost in direct contact, with only a thin layer of connective tissue between them. and without any motion of one upon the other. Such joints connect the bones of the cranium. The bones of the face, except the lower jaw, are also bound together by immovable articulations.

There are three important kinds of movable joints,—*pivot*-joints. *hinge*-joints, and *ball-and-socket* joints.

The *pivot-joint* permits only the motion of rotation. A good example is found in the motion of the atlas on the axis when the head is turned from side to side. The relation of these two bones is shown in Fig. 35. Across the ring of the atlas is a strong ligament which holds the atlas in place and yet permits it to rotate about the odontoid process.

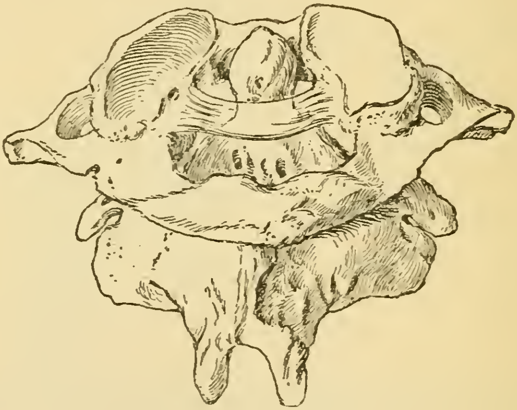

Fig. 35.—Example of pivot-joint. Atlas on axis.

The *hinge-joint* is common in the human body and in the bodies of all higher animals. Only a forward and backward motion in one plane is permitted by a joint of this kind. The motion is like that of a door on its hinges. A good example is found in the last two joints of the fingers. These joints permit the fingers to be closed and opened, but do not admit of any lateral motion. The elbow and knee are also examples of hinge-joints.

The *ball-and-socket* joint allows greater freedom of movement than is possible with any other kind of joint. The best example of such a joint is found in the hip. By reference to Fig. 34 it is plain that, within certain limits, the leg can be moved in any direction desired.

In the shoulder, where the humerus articulates with the scapula, is also a joint of this kind. The socket here is not so deep as that at the hip. As a result of the shallow socket the arms have a greater range of motion than the legs, but the shoulder-joint is more liable to dislocation.

Another kind of joints, called *gliding joints,* may also be mentioned. Examples may be found in the bones of the carpus and tarsus, which may glide slightly upon each other.

Health of joints.—Joints are delicate in structure, and so are liable to disorder unless they receive proper care. A diseased condition of the joints, called *gout,* is common with those who drink strong wine and other alcoholic liquors. The tendency to gout is also often inherited.

Another serious disease, often located in joints, is rheumatism. It is frequently the result of negligence in the matter of clothing suited to changes in the weather. It may be caused by sitting in damp places, or by neglecting to change clothing after exposure to wet. Rheumatism is the cause of a great deal of pain and discomfort, and yields very slowly to any treatment now known.

Joints are liable to sprains and dislocations. When the ligaments about a joint are torn or unduly stretched, the joint is said to be *sprained*. Even slight sprains should receive immediate attention, for neglect may, as has often been the case, result in stiff joints.

When the bones of a joint are forced out of place it is called a dislocation. When this occurs, no time should be lost in calling a surgeon to put the bones in place again.

QUESTIONS FOR REVIEW.

1. Of what use are joints in the human skeleton?
2. What are the three conditions of a good movable joint?
3. How do joints of the body compare with joints of a machine?
4. Describe the use of articular cartilage.
5. How is a joint lubricated?
6. What provision is made for keeping joints in place?
7. Give examples of immovable joints.
8. What kind of joints in the bones of the face?
9. Name three important kinds of movable joints.
10. Describe the motion of the atlas on the axis.
11. What kind of motion in a hinge-joint?
12. Of what advantage is a ball-and-socket joint?
13. What kind of joints are in the tarsus and carpus?
14. What is *gout?* what is one of its causes?
15. What are some of the causes of rheumatism in the joints?
16. What is a *sprain*?
17. What is a *dislocation?*
18. Point out and name each kind of movable joint seen in skeleton on page 34.

CHAPTER VI

MOTION

Motion a test of life.—Animals have the power of voluntary movement. Our common test of life is the ability to move. Some motion, such as the beating of the heart or the act of breathing, is going on in the body at all times. The power of voluntary movement, however, is one of the chief distinguishing marks between the higher animals and the higher plants.

Movement within the cells.—Beside the commonly observed motions of the body, there are also many delicate motions which are never seen except by aid of a strong microscope.

The motion within the cell, as in case of cell division described on page 20, is an evidence of the life of the cell.

The white corpuscle is capable of independent movement, and goes about from place to place within the body.

Another example of cellular movement is found in certain of the epithelial cells which are provided with cilia (Fig. 19). These cilia, some thirty to each cell, are in constant motion, lashing back and forth. This motion is produced by the cell, and continues long after the body as a whole has ceased to live.

Motion by means of muscles.—The principal bodily motions are accomplished by the action of the muscles upon the bones. One important use of the skeleton and its joints is to give the body agility and facility of motion.

The skeleton alone, however, has no power of motion. The power to produce motion resides chiefly in the muscles, which are attached to the bones. They are called *skeletal* muscles. There are also other kinds of muscle, such as those of the heart and arteries, which will be described later.

The two ends of a skeletal muscle are attached to two different bones, which have a movable joint between them. When the muscle contracts, the positions of the bones are changed in their relation to each other. In the diagram (Fig. 36) the muscle is attached at O and I. The joint is at J. When the muscle shortens, the lines A J and B J will be drawn towards each other. If the point O is immovable, all the motion will be made by A J. Such is the plan of most skeletal muscles. It is plain that if the two ends of the muscle were attached

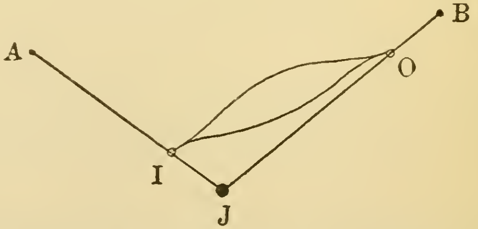

Fig. 36.—Diagram showing how motion is produced by contraction of muscle.

to the same bone its contractions would only tend to strain the bone and tear the muscle.

Shape and attachment of muscles.—Skeletal muscles consist of a soft, red, central part, which tapers off at each end into cords of white fibrous tissue. The cords are called tendons, and they serve as a convenient means for the attachment of muscles to bones. Some muscles, however, are attached directly, without the intervention of tendons.

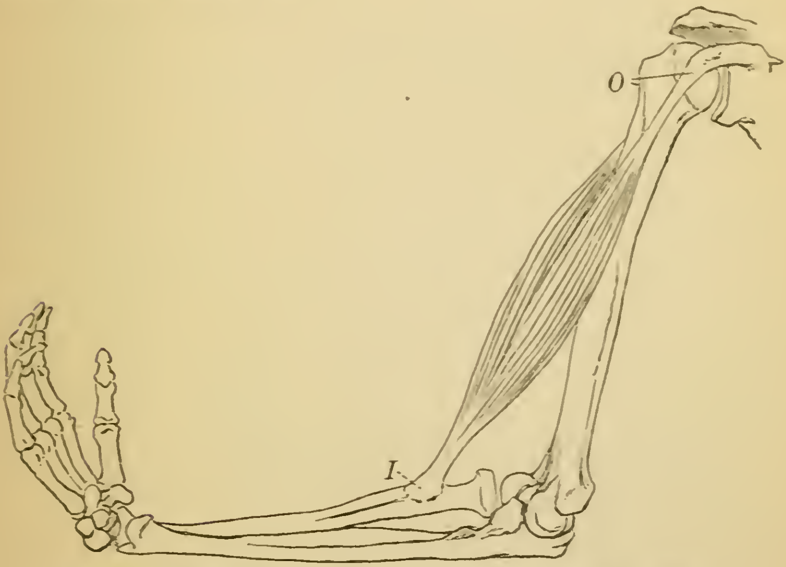

FIG. 37.—Showing bones of the arm and biceps muscle.

In Fig. 37, *O* is called the *origin* of the muscle and *I* the insertion. The origin is the end nearest the centre of the body, and which usually moves the least. In the Fig. is a representation of the muscle called the *biceps*. It is the large muscle of the arm, to which men and boys often point as an evidence of their muscular ability.

It has its origin in the shoulder-blade at *O*, and its insertion at *I*. When it contracts. the forearm and hand are raised.

Mechanical principles in the motions of the skeleton.—The lever is the chief mechanical contrivance for producing the motions of the body: Levers are usually classed as three kinds, the difference depending on the point of attachment of the *weight*, the *power*, and the *fulcrum*. The fulcrum is always the still place, or the axis upon which the lever rotates. Fig. 38 shows three levers of the first class. The bolts show the positions of the fulcrums. The hand shows the point where the power is applied. and the weight or resistance to the power is at the other end.

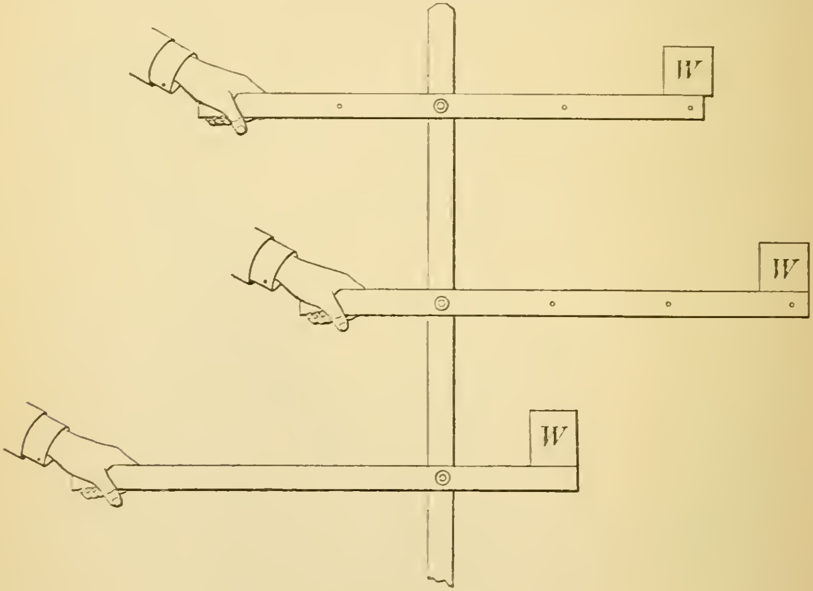

Fig. 38.—Levers of the first class.

In the topmost lever the two arms are equal, and so there is no advantage except that when the hand pushes down the weight goes up.

In the second lever the weight end is much longer than the hand end, and so, when the hand moves down and up, the weight will move up and down, but much farther and faster. With this arrangement the hand can move only a light weight, but it can move it rapidly.

In the third one the hand has the long arm of the lever. The weight may now be heavy, but it can be moved up and down only slowly.

Not much use is made in the body of this first class of levers. An example of it is found in the backward movement of the head. Here the fulcrum is the point where the skull articulates with the atlas. The front part of the head is heavier than the part back of this fulcrum, and so the head will fall forward of itself. But a backward motion is produced by the contraction of muscles which are attached to the backbone below and to the occipital bone above.

In the second class of levers the fulcrum is at one end and the power at the other, with the weight between them. In this arrangement there is a gain in power, and the closer the weight is to the fulcrum the heavier it may be for the same power exerted by the hand, but the weight will move through a smaller distance and less rapidly than the hand does. A good example of this kind of lever is found in the foot. It is used in rising on the toes. Here the toes are the fulcrum, the power is applied at the heel, and the weight of the body is between.

When the strong muscle of the calf contracts, it pulls upon the tendons which are attached to the heel and the body is raised.

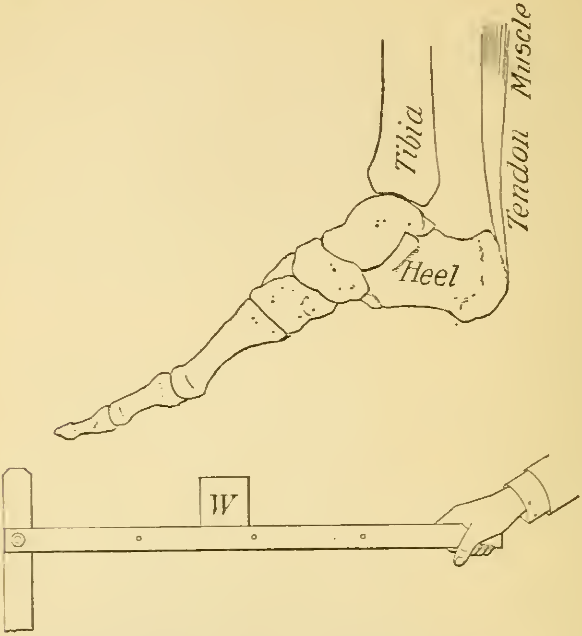

Fig. 39.—Levers of the second class.

Every step we take in walking and running involves the use of this muscle and lever.

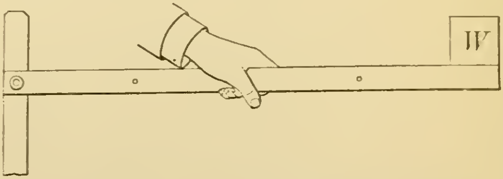

Fig. 40.—Lever of the third class.

Levers of the third class are most common in the body. Here the power is applied between the fulcrum and the weight. The power, in this kind of lever, must always be greater than the weight, or resistance, but there is a gain in the velocity with which the weight is moved. The movement by which the hand is raised to the mouth is accomplished by a lever of this kind.

By reference to Fig. 37 it is seen that the fulcrum is the elbow, the weight is the forearm, the hand, and whatever the hand contains, and the power is applied to the radius a little way below the elbow at the point of insertion of the biceps.

Voluntary muscles.—Muscles are of two kinds, the *voluntary* and the *involuntary*. The *voluntary*, as the word would indicate, are those which are under the control of the mind and can be operated at will.

When you nod in response to an inquiry, we know you mean yes, because the muscles that produce that motion are voluntary. All the skeletal muscles are voluntary.

Each bundle of muscle, as we shall see later, is made up of a great number of cells with the cell material about them. Each cell is connected by a nerve-thread to the nervous centre,—the brain. When we wish any voluntary muscle to do work, a message is sent out along the nerve from the brain to the muscle. The muscle is thus stimulated to activity. Each cell of the muscle contains a store of energy which it gets from the food we eat. When the food material unites with the oxygen which we breathe, the energy is changed to heat and work.

The energy is all in the cell, and the message from the brain only excites the cell to activity. It is not like ring-ing an electric bell by pressing a button, for in that case all the energy passes over the wire to the bell.

The relation of a general to his army is a good illustration of the relation of the brain to the muscle. The energy is in the army, but it may remain perfectly passive until orders are received from the general. The order may set the whole army in motion. Only the stimulus and not the energy came from the general.

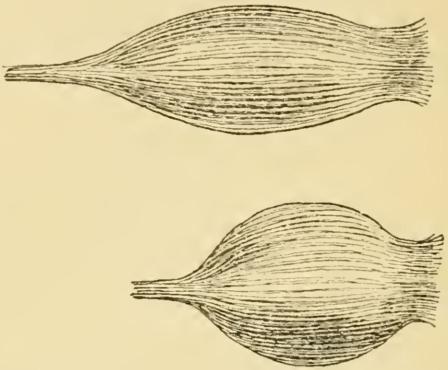

Fig. 41.—Showing the shape of a muscle before and after contraction.

Involuntary muscles.—Involuntary muscles are those over which the mind has no direct control. They are such muscles as are found in the walls of the gullet, and which by contractions force the food down into the stomach. The muscles in the coats of the stomach are of this kind, and after a meal they contract on the food, moving it about and mixing it with the digestive juices. The intestines by a contraction of the muscles in their walls move the food along without any voluntary attention on our part. The action of the heart is beyond the control of the will. Its muscles are therefore involuntary. The muscles which are concerned in the operation of breathing may be called semi-voluntary, for they can, to some extent, be controlled by the will, but breathing will continue while we are asleep, or while we are completely absorbed in other matters.

It must not be thought that these cells move purely of their own accord. They, too, are stimulated by nerves which come from nerve-centres, as will be explained under the discussion of the nervous system.

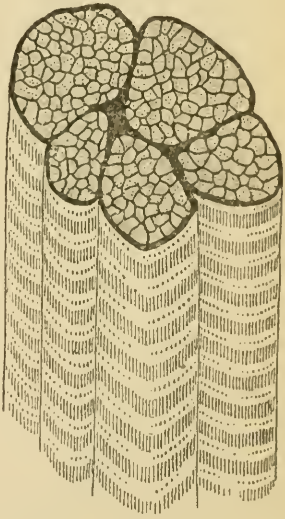

Fig. 42.—Portion of fascia showing five fasciculi and their component fibres.

Structure of voluntary muscle.—The voluntary muscles are put up in bundles called *fasciæ*. The *fasciæ* are bound with connective tissue, and are in turn made up of smaller bundles called *fasciculi*, five of which are shown in Fig. 42. The *fasciculi* are composed of *fibres*, which are the cells and cell material of muscle.

The fibres are composed of a soft substance enclosed in a sheath called the *sarcolemma*. The fibres are small, having an average diameter of about $\frac{1}{600}$ of an inch, while their length varies from $\frac{1}{3}$ to $1\frac{1}{2}$ inches.

A bundle of muscle may be a foot or more long, so that a fibre cannot always reach from end to end of the muscle. In that case the end of one lies between two others that follow, and to which they are cemented by means of the sarcolemma.

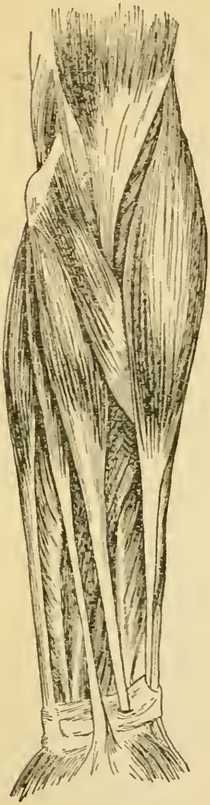

FIG. 43.—Showing muscles of the forearm and their tendons.

At the ends of skeletal muscles the fibres blend into the tendons, or, if there be no tendons, they connect to the bone.

When the fibre is examined by a strong microscope, it is seen to be marked across by very fine alternating bands of dark and light. A bundle of this kind of fibres is called *striped* or *striated* muscle.

Each fibre contains a nucleus, and is connected by a nerve to the brain so that it can be made to contract at will.

Structure of involuntary muscle.—The involuntary muscles are made up of spindle-shaped fibres which are about $\frac{1}{450}$ of an inch in length and about $\frac{1}{4000}$ inch in breadth. Each contains an elongated nucleus.

This kind of muscle is used to surround cavities of the body, chiefly the digestive tract and blood-vessels. As they are not attached to bones, they have no origin or insertion.

The fibres are not striated as in voluntary muscles. They slowly contract under proper stimulus, becoming shorter, and thus changing the capacity of the cavity which they surround.

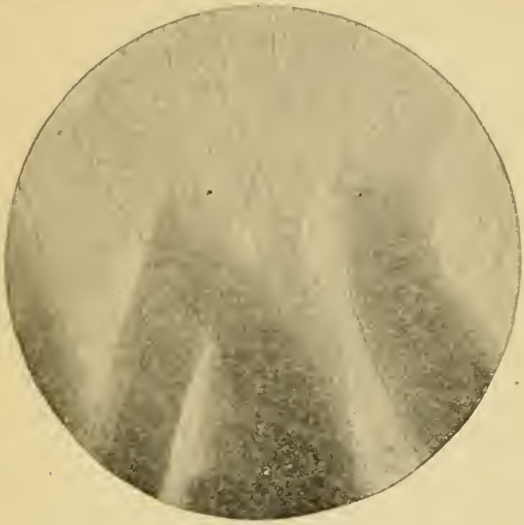

Fig. 44.—Striated muscular fibres.

The fibres of the heart partake of the structure of both kinds of muscle. Its flattened fibres are laced together and are without a sarcolemma, as is the case with involuntary muscles, but the fibres are striped as in voluntary muscles, though not so distinctly.

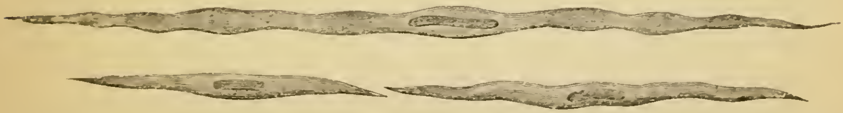

Fig. 45.—Fibres of involuntary muscles.

The development of muscle.—Muscle is capable of high development. Our bodies are made in such a way that when any organ or part of the body is called upon for greater and greater service an effort is made to meet the demand.

When a muscle has been unused for a long time, it degenerates, until but little is left of it, except the connective tissue.

After a broken arm or leg has been in the splints for several weeks, the muscles become so weak that it requires long and careful exercise to bring them back to their former strength.

The brawny arm of the blacksmith, on the other hand, shows the effect of vigorous daily exercise. Exercise is a call for power which nature tries to furnish.

Food of muscle.—Each muscular fibre or cell, as we have already explained, is a little engine capable of converting food into heat and motion. Just like other engines, however. they cannot give out any energy until they first receive it. Good air and good food are necessary to the development of strong and healthy muscle. Without these, exercise is worse than useless.

Development gradual.—Many young people try to develop the muscle too rapidly. They sometimes choose large dumb-bells for their gymnastic exercises and expect to see great results in a few days or weeks. This is a mistaken notion. The true development of either body or mind comes gradually.

Those who are experienced in this matter give more attention to the *regularity* and *persistence* in their practice than to the intensity of it. A strong man can profitably use only a two-pound dumb-bell, but he must practise a certain length of time every day and then rest.

When exercise is carried too far, the muscle becomes exhausted and weakened.

Clothing during exercise.—In a later chapter we shall see that one office of the skin is to throw off waste matter which, if retained in the circulation, would be a poison to the blood. During vigorous exercise the quantity of waste thrown off is much greater than at other times, and for this reason the clothing should be loose and light. The same kind of clothing is also necessary for the freedom of the muscles and to permit the escape of the excess of heat which is always developed by exercise.

Kinds of exercise.—There are a great many kinds of good exercises. The kind, however, is not always so important as the way it is done.

As a rule, it may be said that outdoor exercises are good for bodily development because of the wholesome air and sunshine.

Also those exercises which call into use many muscles of the body are preferable.

Walking is good, inasmuch as it takes one into the open, fresh air ; but if the walk is only a stroll about the streets it fails to call into use many parts of the body. The best kind of a walk is one up and down hills and over fields and fences. A dress parade is of little value.

Those who live near a body of water have at hand a most beneficial kind of exercise in rowing, which should call into full use the muscles of the arms, legs, and back.

Lawn tennis is among the best of outdoor exercises.

Base-ball and foot-ball under a proper director are good kinds of sport, not only for the exercise in the game itself, but also because success comes only to those who take good care of their general health at all times.

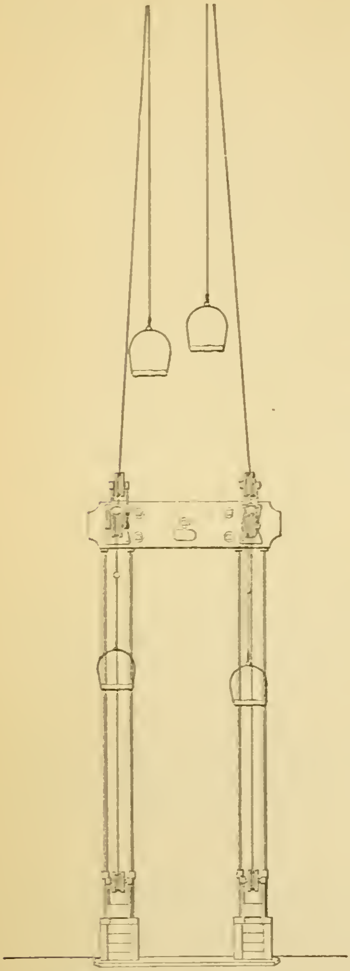

FIG. 46.—Exercisers.

Physical culture.—In recent times there is a demand for *physical culture* apart from any games. This can be secured, under the guidance of a competent director, in the gymnasia of the best schools and colleges.

In any game there are some parts of the body which receive an undue amount of exercise, and other parts which receive none, or not enough for their proper development.

In physical training the development progresses in a systematic and natural manner. The action of the heart, lungs, and muscles are all strengthened. Those who are weak can thus be made fit to engage in strenuous athletic sport without harm to themselves. The general health is improved by such culture, and the chances of disease and sickness are much reduced.

One may obtain such culture at home by use of dumb-bells, Indian clubs, and exercisers such as shown in Fig. 46.

More important than the apparatus, however, is the will-power needed to persist in taking the regular daily exercise.

It is best always to first consult one who is competent to instruct in this art, that the many errors which the unaided novice is sure to make may be avoided.

Whatever the nature of the exercise is, the conditions that should prevail are: good air, many muscles in use, moderation, rest, persistency in effort, and regularity in time.

Skilful muscles.—The development of a strong and healthy body is desirable for several reasons. Such a condition has associated with it a good appetite for food and ability to assimilate it; a vigorous circulation of blood; and deep breathing. Such a condition of body furnishes a good foundation for a vigorous and sustained action of mind. "A sound mind in a sound body" is a true maxim. It is not necessary for this purpose that the muscles be *highly* developed, but that they should receive sufficient exercise to keep them in a healthy and vigorous condition.

A large and strong muscle, however, is, to most people, of no advantage in itself. Such a muscle may strike a heavy blow or lift a great weight, but such things can be done by the brutes. which have still stronger muscles. Man's object must be to acquire skill in the use of his muscle.

A strong muscle that is trained to move the arms, hands. legs, and body in a skilful manner is worth all the time and effort which such training requires.

Effect of alcohol on the muscles.—At one time it was thought that alcohol would add strength to the muscles. Its true nature and effect upon the body were not then known. In these later years a close study of the subject has been made by able scientists and physicians who were interested only in finding out the truth. The evidence in all cases is that the use of alcoholic drinks will lessen the ability of the muscles for sustained work, and the man who relies upon the use of his muscles for a living, cuts down the source of his strength by the use of alcohol.

Of course, other evil effects follow the use of alcohol, but only the effect on muscle is being considered here.

Experiments with the ergograph.—The *ergograph* is an instrument by which it is possible to tell quite exactly any change in the ability of muscles to do work. Experiments with this instrument have shown that with doses as small as one and one-half teaspoonful of alcohol there was at first, for a short time, an increase in work. But soon there was a rapid drop in the scale, so that the total work done was less than without alcohol. Many experiments of this kind indicate that alcohol has a depressing effect upon the muscles.

Experiments with armies.—It was once customary to deal out to soldiers rations of strong drink, such as whiskey, rum, and brandy. This was done because it was believed that the soldier could then endure a longer march and greater fatigue and hardship. Trial has been made with soldiers in the armies of the United States, England, Germany, and other nations, with the use of alcohol and without it.

The results clearly showed that the soldiers without alcohol were in much better physical condition at the end of a hard contest or long march. Those who had taken alcohol would start out more briskly, but would sooner fall by the way.

Alcohol and the railroads.—All good railroads seek to do business on an economical and efficient basis. To do this they must have efficient men. They have found that alcohol, even in moderate quantities, will sooner or later lessen a man's efficiency for service. The officials of a good railroad will not accept the services of a man who is known to drink any kind of alcoholic liquors. Some will not even permit their employees to lodge or board at a hotel which has a bar attached. Similar precautions are taken by all large business firms.

This is not so much because these corporations are interested in the temperance problem, but they want those men who can best do their work. They know from experience that a good man will be better if he is a total abstainer from alcoholic liquors.

Athletics and alcohol.—Those who train for athletic contests, where they will need all the strength and power of endurance they can muster, are required to totally abstain from the use of tobacco and alcohol. Experience has shown the trainers that these two poisons are destructive, and tend to tear down and not to build up.

Even those who follow the ignoble calling of prize fighting are compelled to be total abstainers, at least during their period of training.

A young man who belongs to the boat-crew or foot-ball team of one of the great colleges could not more effectively disgrace himself in the eyes of his fellow-students than by using alcohol or tobacco on the eve of an important contest.

Effect of alcohol on skill.—Most people are not directly concerned in athletic sports, but the same principle that makes it advisable to refrain from alcohol in that case will more forcibly apply in the serious contests of life. The degree of skill needed to make one a success in any art is acquired only by long practice under favorable physical conditions. Alcohol so affects the nerves and muscles that the nerve is not able to deliver a clear-cut order to the muscular cell, or the cell is not able to execute the order. The result is an unsteady and clumsy motion.

It is claimed on good authority that the present commercial supremacy of the United States is in good part due to the fact that there is less drinking among our workmen than among those of European countries. The result must be the acquisition and retention of an artistic skill which results in a better and larger output of goods. The Labor Bureau of the United States shows in its report that a large per cent. of the employers of skilled and unskilled labor require total abstinence on the part of their employees. They are not even willing that their men should drink after their day's work is done, for both experience and exact experimentation have shown that alcoholic drinks taken at night impair working ability the following day.

QUESTIONS FOR REVIEW.

1. What is our common test of life?

2. Describe some movements in the body which we do not ordinarily observe.

3. How are muscles attached in reference to joints? Why?

4. What is meant by *origin* and *insertion* of muscle? Illustrate by reference to the *biceps*.

5. Show the advantages and disadvantages of levers of the first class. Where in the body is this lever used?

6. What is the position of *fulcrum*, *power*, and *weight* in levers of the second class? Give example of its use in the body.

7. When is a lever of the third class? Give example of its use in the body.

8. Which kind of lever is most used in the body? What is the effect on bodily motions?

9. What are voluntary muscles? Where are they located?

10. How are muscles stimulated to activity?

11. Is the energy in the nerves or in the muscles? Illustrate by the relation of a general to his army.

12. Where are the involuntary muscles? Why so called?

13. Explain the structure of voluntary muscles.

14. Explain the structure of involuntary muscles.

15. What is peculiar about the structure of heart muscle?

16. How can muscle be developed?

17. Why do working muscles need food?

18. Why cannot muscle be developed rapidly?

19. What kind of clothing is best during exercise? Why?

20. Name some good exercises. Give reasons.

21. How does physical culture differ from exercise in games?

22. Why is skill desirable?

23. What is the effect of alcohol on muscle?

24. What is shown by the ergograph?

25. What has been the experience with armies?

26. What is the action of railroad officials in regard to alcohol? Why?

27. Why do those who train for athletic contests not drink alcohol?

28. What is the effect of alcohol on skill?

CHAPTER VII

FOODS

The use of food.—Our bodies need food for two purposes, first, to build up and maintain the tissues of the body, and, second, to furnish the energy needed for the *work* we have to perform and the *heat* which must be maintained in the body.

Nature has given to all animals the sensations of hunger and thirst, and an appetite for those things which the tissues need. A perfectly healthy appetite should be a safe guide in choosing food. Most appetites, however, are not reliable, and for this reason, among others, food is a proper subject for intelligent study both as to its nature and its use in the body.

Constant loss of material from the body.—There is constantly being thrown off from the body in various ways a quantity of matter which would be injurious if retained in the body, or which is no longer of any use. Every breath from the lungs carries out considerable water and carbon dioxide ; by perspiration the skin is constantly giving off water and waste ; a large amount of water and urea is excreted by the kidneys ; the undigestible parts of food as well as the undigestible matter which is eaten with food are daily thrown off from the body ; and the surface epithelium is constantly wearing away and falling off. From all such causes the body loses on an average about nine pounds each day.

It is plain that at this rate the body would soon waste away unless food be supplied at the same rate.

The nine pounds a day is for the average healthy body at work at its full capacity. When food is not sufficient to supply the loss, the waste will be less, but the body will be less efficient in the same proportion.

Loss of energy.—The old idea of food was that it was only for the purpose of supplying the tissues with material for their growth and repair, and to lubricate the moving parts. The real nature of food was not understood. We now know that the chief function of food is to supply energy. Every motion and action of the body, even thinking itself, is a use of energy which was in the food. When the body does any work it must lose a certain amount of energy, and is to that extent less able to do other work.

When the body does very little work, not so much food need be eaten, for the energy from the food last taken has not yet been expended. When much work is done the energy is soon exhausted, and we are made aware of the fact by the sensation of hunger.

Two kinds of energy.—There are two kinds of energy, called the *potential* and the *kinetic*. The water in a dam has potential energy because it would flow down the valley if the dam were removed. A weight on a shelf has potential energy because it will fall if the shelf is removed. Coal has a potential energy because it has a strong affinity for oxygen and will unite with it, producing the intense heat of combustion. Material bodies in general possess potential energy by virtue of their position or chemical character. Food contains potential energy because in the body it combines with oxygen and is changed to other substances.

The result of all such changes is the *energy of motion* which is called *kinetic* energy.

The main purpose of food is that we may take into our bodies potential energy, which may there be converted into kinetic or moving energy by means of which we move, work, think, and keep warm.

There is a large amount of energy in the world, and the amount never grows any larger or smaller as a result of any changes which we can bring about.

Our chief concern must be to keep the body in such a state of health that the necessary amount of energy may be appropriated by it and made to do useful work.

Comparison with steam-engine.—The relation of coal to the steam-engine may serve in part as an illustration of how food is converted into ability to do work. The fuel—coal, wood, or gas—is made to unite with oxygen under the boiler. An intense heat is generated, which is carried by the steam to the engines, and there converted into the motions of the machines of the mills and factories.

After the fire is once started, the boilers and engine, if kept in repair, will continue to do the work to which they are adapted as long as they receive their proper food, which is coal or some form of carbon.

When the fireman cuts off the supply of fuel, the engine runs slower and slower, and finally becomes still and cold.

While the engine is running, its whole operation consists in getting energy from the fuel and passing it on in some form to other objects upon which it does work.

The coal is the source of the energy of the engine in about the same way that food is the source of the energy of the human body. The method by which the change is brought about, however, is different in many particulars.

Oxidation in the human body.—The one important particular in which the coal of the engine and the food of the body are exactly alike is the strong affinity of both for oxygen. Their potential energy consists in the fact that they can be *oxidized*, that is, they will combine with oxygen, or burn. By this process the energy is made available.

In the case of the engine the fuel is all oxidized rapidly and with intense heat at one place, that is, in the fire-box. In the body oxidation takes place slowly and in all parts of the body. Food is carried in the stream of blood to all the cells and there, for the most part, it is burned, and its potential energy becomes kinetic or moving energy. The most of the oxidation occurs in those cells which are most concerned in the performance of work, as in the muscles.

Oxidation within the body does not result in a high temperature like that from burning wood or coal. In fact, it is quite certain that much of the energy of food is converted into the energy of motion without any heating. Some of it is converted into heat energy, and thus the temperature at which the body can best live is maintained.

The difference in the rapidity of oxidation, such as occurs in a stove, and that within the body, may be illustrated by use of a magnesium ribbon. When a piece is lighted in the open air it will rapidly oxidize, that is, burn. A piece of the same material placed in a bottle and moistened with a few drops of water will also completely oxidize, but will require several days to do so. The total amount of heat produced is the same in both cases if the same amount of material is used.

Composition of the body.—The tissues of the body are found to be composed mainly of four elements, —*carbon*, *hydrogen*, *oxygen*, and *nitrogen*. In addition to these a number of other elements are also found, though in less quantity. They are *sulphur*, *phosphorus*, *chlorine*, *sodium*, *potassium*, *calcium*, *magnesium*, and *iron*.

The three main compounds in the body.—The elements named above do not exist separately in the tissues, but are united in a variety of ways forming compounds. The most important compound is *proteid*. It is found only in live matter of animals and plants, and is composed of carbon, oxygen, nitrogen, hydrogen, and sulphur. A good example of a proteid is the white of an egg. It is important to notice that proteid contains nitrogen.

The second class of important compounds in the body are the *carbohydrates.* These are composed of *carbon, hydrogen,* and *oxygen,* but no nitrogen. One important carbohydrate is *glycogen,* which is found in large quantities in the liver. Others are *grape sugar, muscle sugar,* and *milk sugar.* These are all closely related to starch, from which they can be made.

The third important compound is *fat.* This substance, like the carbohydrates, is composed only of carbon, hydrogen, and oxygen, but in different proportion. The quantity of fat in the body varies greatly in different individuals and in the same individual at different times, but the average quantity in a man is about six pounds.

Other substances in the body.—The three classes of substances just named are the important organic compounds of the body. There are also several other substances which are not important in themselves, but which are indispensable because of the assistance they give in the processes of life.

Water constitutes about two-thirds of the weight of the body. If a man weighs one hundred and fifty pounds, one hundred pounds are water. Every tissue of the body contains some water. Even the enamel of the teeth, the hardest substance in the body, is 2 per cent. water. Muscle is three-fourths water. Bone is about 22 per cent. water, and saliva is almost pure water.

Salt is found in all tissues of the body.

Phosphate and carbonate of lime are the chief constituents of the bones and the teeth.

A number of other compounds are also found in the body.

What is a food.—Foods should be such substances as will supply the material of which we find the body is composed. A substance is not a food simply because it contains elements which are found in the body, but it must be of such a character that it can be digested and made a part of the body. *A food is anything which, when taken into the blood, will supply the needs of the body without doing it harm.*

Food of the body a complex compound.—Carbon is an important element in food, but carbon alone is not a food. Charcoal is almost pure carbon, but it cannot be digested or in any way become a part of the body. Neither can the body make any use of hydrogen or nitrogen as foods. Oxygen is the only element which, when uncombined with other elements, may be considered a food.

The chemist writes $C_6H_{12}O_6$ as the symbol for grape sugar. When the carbon, hydrogen, and oxygen are united in this kind of a complex compound, the body can use them as food. In the body the sugar unites with the oxygen which we breathe, and the result is a breaking down of the sugar compound into the simpler substances, water and carbon dioxide. In this way the energy which was in the sugar is set free for work or heat.

The compounds of fats and proteids are still more complex than that of sugar, but they, too, unite with oxygen, and are broken up into simpler compounds with the like result of a liberation of energy.

Three classes of foods.—*Proteid* is an essential food. It alone contains the nitrogen of food, and is the chief source of supply of that element to the body. Proteid is built up by vegetables. From this source animals obtain it. Lean meat is rich in proteid. Since man's food consists of both meat and vegetables, he gets proteid from both sources.

The chief sources of proteid are meat, milk, eggs, and vegetables.—principally wheat.

The *carbohydrates* of food are chiefly obtained direct from the starch and sugar which are stored up in vegetables. The chief sources are wheat, rice, and other cereals, potatoes, fruit, cane sugar and grape sugar.

The *fats* of food are obtained from a variety of sources, such as fat meats, butter, cream, and oils.

Wheat as a food.—Bread is often called "the staff of life." An examination of a grain of wheat shows that it is rich in the foods just described. It contains about 14 per cent. of proteids, 57 per cent. of starch, 5 per cent. of grape sugar, 2 per cent. of fats, and many other substances in small quantity.

The proteid of wheat is mainly the gluten. It is this which makes the dough sticky and tenacious.

When yeast is added to the mass of dough it begins to ferment and form alcohol and carbon dioxide. In this way bubbles of gas are formed in every part of the dough and are held in by the tenacious gluten. The formation of the gas causes the bread to "rise." In the hot oven the bread rises rapidly because the heat causes a rapid expansion of the gas. When it is baked the gas can escape, but the bread retains the light and porous character given to it by the bubbles of gas.

Wheat contains more gluten than any other cereal, and consequently its flour can be most easily made into light bread.

Corn.—Corn contains only a little more than half as much of the proteids as compared with wheat, but a greater per cent. of starch, and it is the richest of all cereals in fats. Corn holds a place along with wheat as one of the valuable vegetable foods.

Some other vegetables.—Peas and beans are about half starch, but they are rich in proteids, containing about 25 per cent.

Rice is about four-fifths starch, but is poor in proteids. Rice alone is a poor diet.

Potatoes are poor in both proteids and starch.

Many fresh vegetables are valuable articles of diet, though they are mainly composed of water and salts. That the body needs them is shown by the fact that a disease called scurvy will break out among those who are compelled to eat only meats. Such has often been the case with sailors on a long voyage, or men in other situations where they cannot get fresh vegetables.

Animal food.—A very common food is the flesh of animals. This consists of muscles, fat, and the various other tissues mingled with them. Flesh is rich in proteid of various kinds, the chief one being *myosin*. Gelatin is derived from the white fibrous tissue. Several mineral foods are also obtained from meats.

Good meat that is well cooked is a valuable food for adults, particularly for those engaged in heavy work or severe exercise.

Eggs are rich in proteid, both the "white" and the "yellow." All the food material necessary for starting the chick are in the egg.

Milk is nature's food-mixture, and is a complete food for infants. For adults it is not a complete food, as it does not contain the various kinds of food in the proper proportion. From milk we get cream and butter, which are the fats; milk sugar, which is a carbohydrate; and casein, or cheese, which is the proteid.

The need of a mixed food.—Some foods contain all the different kinds needed by the body, but not in the right proportion. No one food makes a complete diet, except milk for infants. It is estimated that a man doing a moderate amount of work will use up about 4000 grains of carbon and 300 grains of nitrogen each day. He will then need food which contains this amount of these elements. If he takes more carbon or nitrogen than the body needs, the excess will not only do the body no good, but will add to the labor of the various organs to get rid of it.

For example, meat alone in sufficient quantity to yield the necessary amount of carbon would also yield three times the amount of nitrogen needed. When meat is eaten with bread and other vegetables the proper proportion of the food elements may be supplied without the excess of any one.

Amount of food.—Most food is eaten for the energy it contains, and the work which it enables a man to do. It is evident, then, that a man needs more food when he is hard at work than when he is at rest or engaged only in mild forms of exercise.

As to how much food the body needs, it is not yet possible to give a definite answer. The authorities do not agree on this matter. It is quite certain, however, that most people err in eating too much rather than too little. According to a standard which has been largely followed, it is assumed that a man doing moderate work would need 118 grams of proteid, 56 grams of fat, and 500 grams of carbohydrates per day.

The total fuel value of this amount of food is 3055 large calories.*

Recent experiments would indicate that an amount of food whose fuel value is only 1600 large calories is, when properly digested and assimilated, better both for health and ability to do strenuous work.

If excess of food were only so much matter to be refused and cast off by the body, it would not be a matter of particular concern. But the organs of digestion and excretion make an effort to handle all of it. They are overtaxed, and none of their work is done well. Such ill-prepared food may even be a poison to the tissues and work great evil to the health of the body.

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* A large calorie is the amount of heat needed to raise the temperature of one kilogram of water one degree centigrade.

The cooking of foods.—Cooking is practised by all civilized people, and is indispensable in the preparation of certain kinds of food. The carbohydrates, which are mainly starch, form the larger bulk of foods. When the starch is cooked, it is much more readily soluble in the juices employed in its digestion.

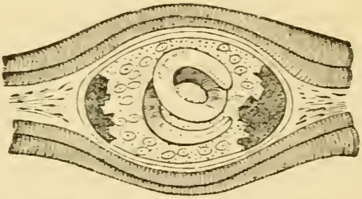


FIG. 47.—Trichinæ in pork.

Meats are not only more palatable when properly prepared in the kitchen, but the tissues are softened, and can be more finely divided by mastication, and more readily dissolved by the gastric juice in the stomach.

Another good reason for cooking some foods is that any minute living organisms which might be present may be destroyed by the intense heat. This is particularly true of pork. In Fig. 47 is a specimen of diseased pork, as it appears under the microscope, showing trichinæ coiled up in the tissue. These, if eaten, may lodge in the tissues of the body. Thorough cooking will kill them.

Rules and methods of cooking cannot be given in a book of this character. Many books are written and schools established for instruction in this useful art. A *general* knowledge of the best ways to prepare food would be of the greatest value to the human race.

Is alcohol a food?—Any substance which at first seems to supply the body's needs, but which in time works a serious injury, is not a food.

The symbol which the chemist uses for alcohol is C_2H_6O. Since carbon, hydrogen, and oxygen are essential parts of the tissues of the body and of our foods, it might at first appear that alcohol would be a desirable food.

When we consider a number of other compounds, however, which also contain elements found in the body, but which we know to be poisonous, we see that our inference in regard to alcohol is not correct. Hydrocyanic acid, for example, is a deadly poison. A very small quantity of it will kill almost instantly, and yet it is made up of hydrogen, carbon, and nitrogen, its symbol being HCN.

Again, we know that alcohol will oxidize,—that is, it will burn and yield heat and energy.

Alcohol will also oxidize in the human body and yield a certain amount of heat and energy. Since this is one of the most important functions of food, it would appear that alcohol would be a food.

A true food, however, will yield heat and energy without doing any harm to the organs and tissues of the body. Alcohol, while it yields heat and energy, acts at the same time as a poison. For this reason alcohol cannot be classified as a food.

This may be illustrated in this way: It is well known that when sulphuric acid and water are mixed together in about equal parts, the mixture will become very hot. This acid will also corrode and "eat up" iron. Suppose now that an engineer should adopt the plan of mixing sulphuric acid with the water in the boiler when he wanted to "get up" steam. The water would be rapidly heated, and, to an ignorant person. this would seem to be a good plan. It would soon be found. however, that the material of the engine was being rapidly destroyed by the acid, and either this method of getting energy would have to be discontinued or the boiler would soon need to go to the shop for repairs or be abandoned altogether.

QUESTIONS FOR REVIEW.

1. State the two chief purposes of food.
2. What are some of the ways by which the body loses in weight?
3. What was an old idea about the purpose of food?
4. Why does a man get hungry sooner when he works than when he is idle?
5. What are the two kinds of energy?
6. Explain what is meant by potential energy.
7. How does a steam-engine get its energy?
8. What difference in the use of food in a steam-engine and in man?
9. How does the body get energy from food?
10. Where did the food get its energy?
11. What difference in the kind of oxidation in an engine and in a human body?

12. Name the four elements of which the body is largely composed. Name several others.

13. What are the three chief compounds of the body? What is their composition?

14. How much of the body is water?

15. Define a food.

16. Why must the food of the body be complex compounds?

17. What element of food is found only in proteid?

18. How are proteids formed?

19. What kinds of foods furnish us with proteids?

20. What kind of foods furnish carbohydrates?

21. What is the source of fats?

22. What makes wheat a good food?

23. Explain the rising of bread.

24. How does corn differ from wheat as a food?

25. What shows that the body needs fresh vegetable food?

26. Name and tell the value of several animal foods.

27. Why is a mixed diet necessary?

28. How much should one eat?

29. What evil results follow from excessive eating?

30. What is the use of cooking?

31. How can proper methods of cooking be learned?

32. What are trichinæ?

33. Is alcohol a food? What makes it seem to be a food? Why is it not a food?

34. What will a good food do for a body?

35. How does alcohol differ from a food?

36. Illustrate by the action of sulphuric acid on the boiler of an engine.

EXPERIMENTS.

Test for proteid.—The white of an egg is nearly pure proteid. Stir the white of an egg into about one-half pint of water, and filter. Put some of the solution into a test-tube or bottle and add to it some nitric acid. Note the change to a yellow color. Add ammonia and the color will change to an orange.

This test for proteid can be applied to meats, wheat, corn, and other substances.

Test for carbohydrates.—Prepare some starch paste by boiling a little corn-starch in water. Add a little of the starch to a test-tube full of water and shake well. Add to this a drop of the tincture of iodine and the liquid will turn blue. This is a test for starch, and may be applied to potato, flour, and other substances containing starch.

Slow and rapid oxidation.—The experiment alluded to in the text of burning magnesium ribbon is performed by holding a piece of the ribbon, one or two inches in length, with pliers, and lighting it with a match. The light is brilliant. but the combustion is quiet and safe. The slow combustion is similar to what is called rust in case of iron. and may require a week or two.

Heat from a mixture of sulphuric acid and water.—Fill a test-tube or small bottle half full of water and pour into it slowly about the same amount of strong sulphuric acid. The bottle will become so hot that it cannot be held in the hand. This acid must be handled with care. To carry out the illustration suggested in the last paragraph of this chapter. add some carpet-tacks or small pieces of iron to the mixture and note the rapid corrosion of the iron.

CHAPTER VIII

DIGESTION

What digestion is.—Digestion of food is a process by which food is so changed that it can be taken into the blood-vessels of the body. For example, we eat a great deal of starch, but, although it may be in the stomach or intestines, it will be of no benefit to the body as long as it is starch.

The starch must be changed to sugar by certain juices that are poured out upon it in the intestines, and the sugar is then easily dissolved and can be passed through the cells in the wall of the intestines and into the blood-vessels close by. Such a change in the character of food is called digestion.

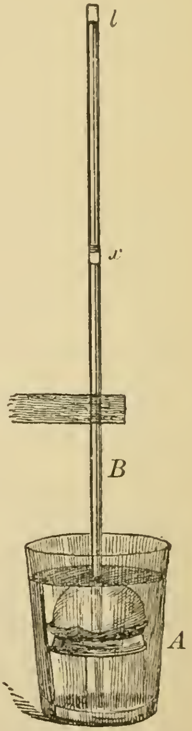


FIG. 48.—Apparatus to show osmosis of liquids.

Why digestion is necessary.—Food must not only be in solution, as just explained, but the solution must be of a certain kind. Most of it gets through the walls of the intestines by a process called *osmosis*. In Fig. 48 is shown a simple apparatus to illustrate this principle.

A is a vessel partly filled with water. B is a thistle tube, over the bottom of which is tied a piece of any animal membrane, such as bladder or the casing taken from bologna. B is then partly filled with, say, a strong solution of salt and suspended in the water. After a time the liquid in B will rise in height and the water in A will become slightly salt. This shows that there is a movement of the liquids through the membrane in both directions, but more rapidly into B. In the apparatus shown, copper sulphate was used in the tube, and the liquid raised from the point *x* to *l* and flowed over the top.

Any solutions that will diffuse into each other will pass through such a partition, when placed between them, even more readily than without it.

While the food is in the intestine, a thin septa of this kind is between it and the blood. The food passes through by osmosis.

After the food is carried by the blood-vessels to the various parts of the body, it passes out to the cells by a similar process. Digestion must change foods to a solution which is capable of this kind of diffusion.

The fats are not digested in this manner, but they get into the blood by being passed in fine droplets through the body of the cells that line the intestines,—a process not yet understood.

The alimentary tract.—The alimentary or digestive tract may be considered a long tube through which the food is made to pass. As the food is pushed along, it is acted upon by the various digestive fluids, which change it to a condition suitable for introduction into the body. While the food is in the tube it is still on the outside of the body proper, for the tube is only an opening through the body. Food is not in the body until it is taken up by the blood.

The entire tract is lined with mucous membrane.

The parts of the alimentary tract are the *mouth*, *fauces*, *pharynx*, *œsophagus*, *stomach*, *small intestines*, and *large intestines*.

The mouth.—The mouth may be considered the gateway to the digestive tract. It is here that we can exercise our will as to the kind and character of the food which we will take.

After food is swallowed, digestion is carried on without any attention on our part. In the mouth occur the first two acts of digestion. These are *mastication* and *insalivation*.

Mastication. The teeth.—The part of the mouth concerned in the first step in digestion is the teeth. The front teeth bite off morsels of food and the back teeth grind the food into fine bits.

Since the proper food for infants is milk, teeth do not appear until about the age of six months. At that age a *temporary* set of teeth begin to cut through the gums one after another, until at about two years of age there are ten teeth in each jaw.

These do not last long, for soon a *permanent* set starts beneath them, and at the age of five or six years begin to push out the first set and to take their places. At the age of twelve or thirteen years all the permanent teeth have appeared except the back ones, which are called wisdom teeth, and which do not come till the age of twenty or twenty-five years.

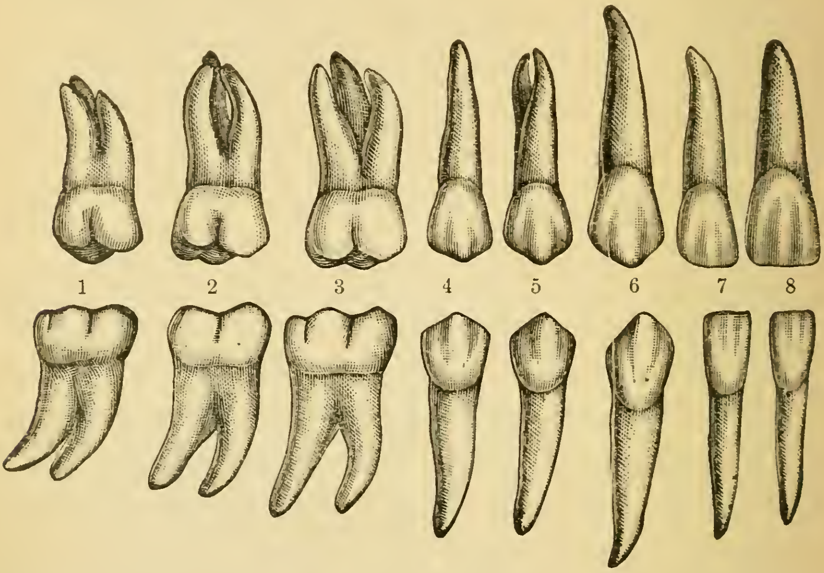


FIG. 49.—Permanent teeth of the right side. (Gray.) 1, 2, and 3, molars; 4 and 5, bicuspids; 6, canine; 7 and 8, incisors.

The full set numbers sixteen in each jaw, making thirty-two in all. In each jaw the four front teeth are called *incisors;* the next two, one on each side, are the *canines;* the next two on each side are *bicuspids;* the last three on each side are the *molars.*

Composition of teeth.—Teeth are made of a hard material similar to bone. They are composed of a *crown*, which is that part extending beyond the gums;

the *neck*, which is surrounded by the gums; and the *root*, which is embedded in the bone of the jaw and firmly fixed with cement.

A cross-section of a tooth shows that it is composed of three parts. In the centre is the pulp-cavity, which is filled with a net-work of blood-vessels and nerves.

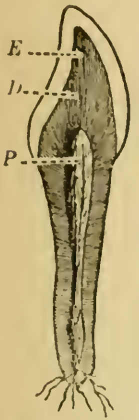


FIG. 50.—Longitudinal section of tooth. *E*, enamel; *D*, dentine; *P*, pulp.

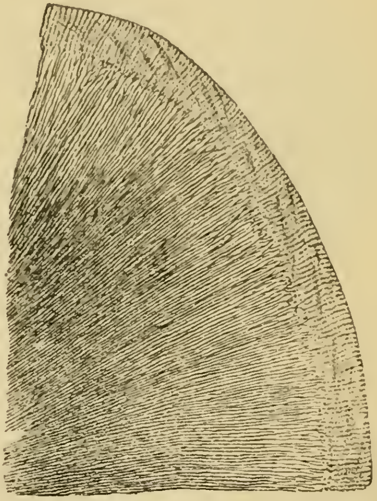


FIG. 51.—Cross-section of tooth, magnified, showing enamel.

Surrounding the pulp is the *dentine*, which is very hard, and yet is alive and composed of fibres radiating from the pulp and receiving nourishment from the blood that circulates through the pulp-cavity.

Enamel covers the crown of the tooth and is thickest on the grinding surface. It is the hardest substance in the body, and can withstand a great deal of grinding without wearing away. Fig. 51 shows a very thin section of tooth as it appeared under the microscope.

Salivary glands.—The process of grinding the food between the teeth is called mastication. While food is being masticated, a fluid called *saliva* is poured out into the mouth through ducts from the salivary glands.

There are three sets of these glands. They are the *parotid*, *submaxillary*, and *sublingual*,—two of each kind.

The parotid glands are situated just below and in front of the ears, and the ducts from them open into the mouth on the inner surface of the cheek, near the second molar tooth of the upper jaw. The submaxillary and sublingual glands are situated beneath the tongue, and empty into the mouth just under the tongue.

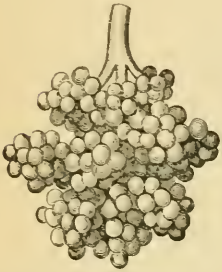


Fig. 52.—Racemose gland.

These are called *racemose* glands, because they consist of sacks all connected together and giving the whole the appearance of a bunch of grapes, as shown in Fig. 52.

The purpose and nature of saliva.—The office of saliva is, first, to keep the mouth moist at all times; second, to moisten the food so that it may be more thoroughly masticated and afterwards swallowed; third, to dissolve some of the foods that are already soluble; and, fourth, to begin the change of starch to sugar.

Saliva is almost pure water, but it contains a ferment called *ptyalin*, which causes the change of starch to sugar.

Ptyalin is not a living organism, like a yeast ferment.

It can change an indefinite quantity of starch to sugar without itself wasting away, and so only a small quantity is needed.

The "ropy" character of the saliva in the mouth is due to the secretions of the mucous membrane which lines the mouth.

The fauces.—After the food has been masticated and mixed with saliva, it is pushed by the tongue through the fauces,—an opening in the back part of the mouth. The fauces is surrounded by the *soft palate* and *uvula* above, the base of the tongue below, and *pillars* of muscles and the *tonsils* at the sides.

The *uvula* is at the centre above and hangs lower than the soft palate.

The tonsils are small glands that secrete mucus.

The pharynx.—After passing the fauces the food reaches the *pharynx.* The pharynx is a centre for a number of passages which radiate from it. It is somewhat conical in shape, with the small end downward.

From it are seven openings: one into the larynx, leading to the lungs; one into the gullet, leading to the stomach; one into the mouth; two into the nostrils; two into the Eustachian tubes, communicating with the drums of the ears.

At the top of the windpipe is a plate of cartilage called the *epiglottis.* This is raised during breathing, but shuts down like a lid when food is being swallowed.

The epiglottis can be seen if the mouth be widely opened and the tongue pressed down.

The œsophagus. Deglutition.—The œsophagus is a tube leading from the pharynx down through the chest to the stomach. It lies near the spinal column, and at its lower end it pierces the diaphragm and enters the stomach just beneath. It is composed of two layers of muscle, the fibres of one running lengthwise, and of the other around the tube. It is lined with mucous membrane.

After food has once entered the œsophagus it is forced down by an involuntary contraction of the muscles just above it. It is not possible to perform the act of swallowing unless there is something to swallow, as may be shown by swallowing three or four times in quick succession, until all saliva is removed from the mouth.

The act of swallowing is called *deglutition.*

The stomach.—The stomach may be considered a place where the alimentary tract is expanded into a pouch. Here the food is, for a time, arrested in its progress along the tract.

The stomach is situated on the left side of the body, just beneath the heart. When fairly well filled it is about ten inches long and five inches through its widest part. It has two openings. One is called the *cardiac orifice,* where the food enters, Fig. 53, *c.* The other is called the *pylorus, p.* A ring of muscle about the pylorus keeps it closed except when food is ready to pass through it. The stomach has four coats, called the *serous* (see page 29), the *muscular*, the *areolar* (see page 26), and the *mucous*. The last named is the coat next to the contents of the stomach.

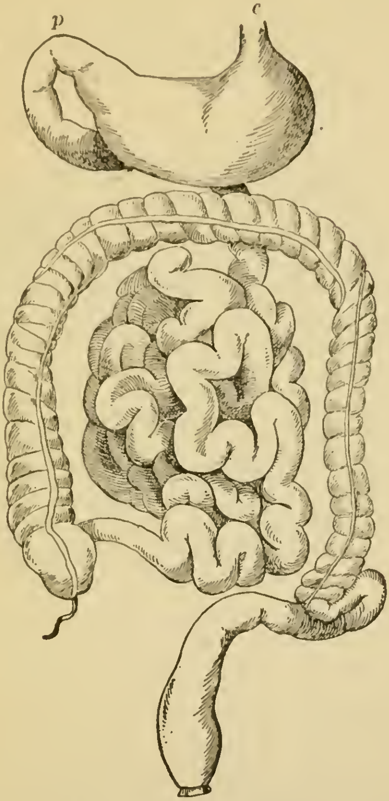


Fig. 53.—Stomach and intestines.

The muscular coat is composed of three layers. In the outside one the fibres run lengthwise, in the next they pass around the stomach, in the third the fibres radiate obliquely from the cardiac orifice, but do not form a complete layer.

The *peritoneum* (see page 30) suspends the stomach as in a sling, and between its folds blood-vessels run to the stomach.

The mucous coat.—The mucous coat is the most important of the four coats of the stomach. When examined with a microscope of only moderate power it is seen to have a honeycomb appearance, caused by the minute shallow pits that cover its surface. In each pit is the mouth of a *gastric gland.* These glands are minute tubes, packed in between the columnar epithelium cells. (See page 24.) They secrete the gastric juice which effects the stomach digestion.

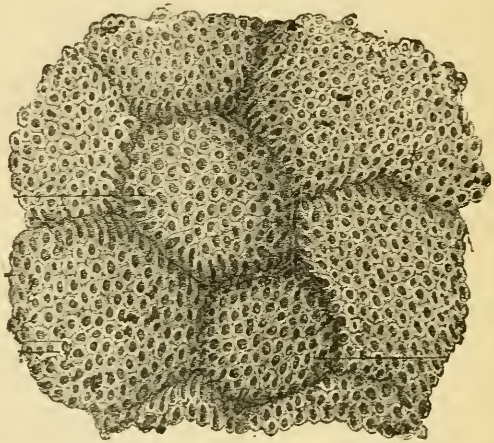


Fig. 54.—Mucous coat of stomach, epithelial layer removed, showing the openings of the gastric glands.

Digestion in the stomach.—While the food is being masticated the *gastric juice* is being secreted and poured out into the stomach, ready for the food when it arrives. Secretion of gastric juice continues during digestion. The saliva is an alkaline substance, but gastric juice is strongly acid in its reaction, so that the conversion of starch to sugar by the saliva ceases while the food is in the stomach.

Gastric juice is composed of *pepsin*, *rennin*, *water*, and about .2 per cent. of *hydrochloric acid.*

The pepsin converts the proteids into *peptones*, and in that condition they can pass by osmosis through the membranes that line the alimentary tract.

The rennin coagulates the casein of milk and the pepsin then converts it also to peptone.

The starches are not changed in the stomach.

The albuminous walls of the fat cells are dissolved away, but the fat is not changed.

The presence of food stimulates the muscular walls of the stomach to action. By their alternate contraction and relaxation they produce a movement called *peristaltic motion*. By this means the contents of the stomach are moved about and thoroughly mixed together.

The mass of food, after it has been digested in the stomach for some time, is of about the consistency of thick cream, and is called *chyme.*

From time to time, as the digestion of the proteids is completed, the pylorus opens and lets the chyme through. In from two to four hours the stomach is empty again.

The small intestine.—The small intestine is about twenty feet in length, though varying considerably in different persons. It begins at the pyloric orifice of the stomach, where it is largest, and ends at the large intestine. The first ten inches of it is called the *duodenum* (twelve) because it is about as long as twelve fingers placed side by side. The next eight feet of it is called the *jejunum* (empty). The remainder is called the *ileum* (twisted) because of its many folds.

Like the stomach, the small intestine is composed of four coats,—the *serous, muscular, areolar*, and *mucous.*

The serous coat is formed by folds of the *peritoneum.* These folds are called the *mesentery*, and they serve both to support the intestines and to conduct the blood-vessels to them.

The muscular coat has two layers, one running lengthwise and the other being circular. The circular is stronger and of more importance.

The mucous coat.—The mucous coat of the small intestine lies in the permanent folds or ridges called *valvulæ conniventes* which pass transversely around the intestines. They prevent a too rapid passage of food along the intestine and present a larger surface for absorption.

On the inner surface of the mucous coat are small projections called *villi.* These are only about $\frac{1}{10}$ of an inch long, but they stand close together, giving the surface a velvety appearance. In Fig. 55 is shown a section of the small intestine of a cat. As the section is very thin and is magnified, the villi do not have their natural, crowded appearance.

In Fig. 56 is shown a few villi of the same specimen as above, but more highly magnified. The dark lines show the blood-vessels, which are here filled with a colored substance.

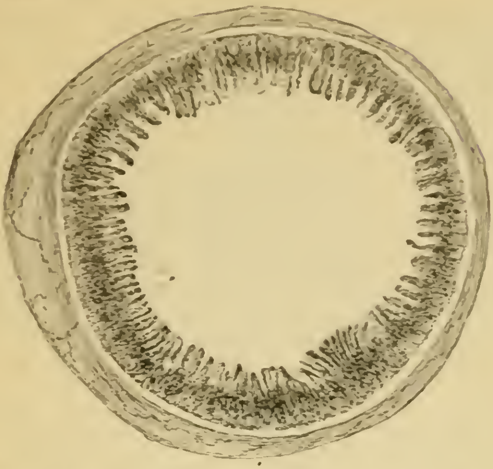


FIG. 55.—Section of small intestine of cat.

When a villus is closely examined, it is found to be covered with a layer of epithelial cells as shown in Fig. 57.

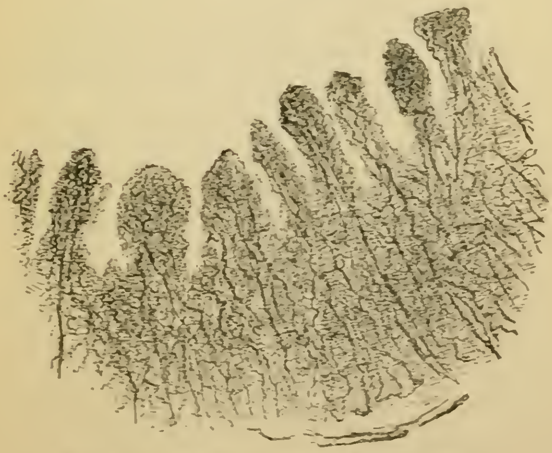


FIG. 56.—Microphotograph of villi.

Within is a net-work of vessels to receive and carry away the liquids that pass through the layer of cells. In the centre, *L*, is a tube called a *lacteal*, which, during digestion, is filled with a milky white liquid. About the lacteal are the capillary blood-vessels.

Here and there between the villi are the mouths of glands called the crypts of Lieberkühn.

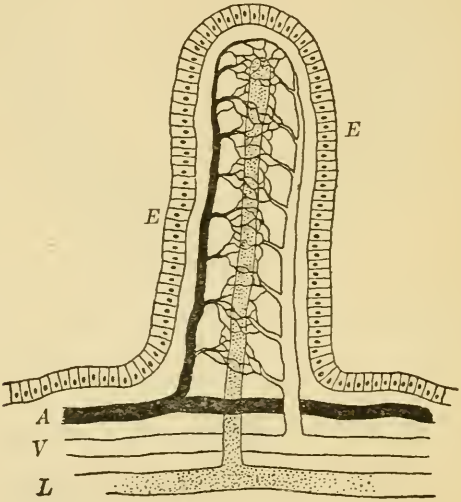


Fig. 57.—Diagram of villus. *E*, layer of epithelial cells ; *A*, artery ; *V*, vein ; *L*, lacteal.

The liver.—Two large glands concerned in intestinal digestion are set off from the alimentary tract, but connect with it by means of ducts, through which they pour their secretions into the small intestine. These glands are the *liver* and the *pancreas*.

The liver is the largest gland in the body and weighs from three to four pounds. It is situated on the right side of the abdomen, just below the diaphragm, and consists of five lobes. It contains a net-work of tubes, through which the blood and other liquids circulate.

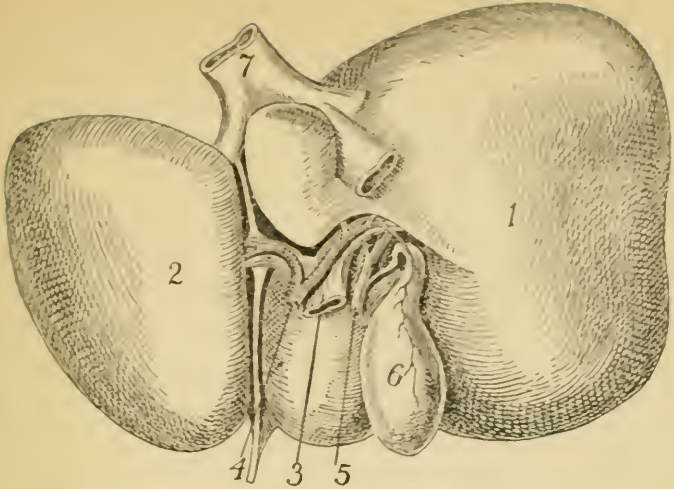


Fig. 58.—External view of liver. 1, right lobe; 2, left lobe; 3, portal vein; 4, hepatic artery; 5, bile duct; 6, gall-bladder; 7, inferior vena cava.

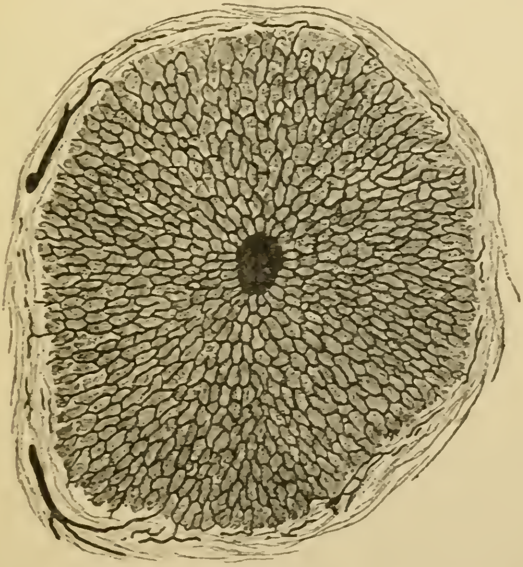


Fig. 59.—Lobule of the liver. Blood is brought by portal vein to outer surface of the lobule and flows through the lobule to its centre, where it is collected by the hepatic vein and conducted to the inferior vena cava.

On close examination it is seen that the liver is made up of a great number of masses called *lobules*. Each lobule consists of hepatic or liver cells, between which run numerous fine blood-tubes. The work of the liver is done by these cells. In Fig. 59 is seen a cross-section of a lobule highly magnified.

The liver is of great service to the body in several ways. In this chapter we are interested in its ability to produce *bile*. This substance is gathered up by numerous hepatic ducts, which finally unite and pour the bile into the duodenum.

Beneath the liver is a gall-bladder, in which the gall is stored when not needed for digestion.

The pancreas.—The other large gland concerned in digestion is the *pancreas*. It is situated in the abdomen back of the stomach. It is a racemose gland and resembles those that secrete saliva. It is six to eight inches long, but quite narrow and thin, weighing only from two to four ounces.

Its function is to secrete *pancreatic juice*, which is poured through a duct that opens into the bile duct just before it reaches the duodenum.

Digestion in the small intestine.—While the food is passing through the process of gastric digestion, the glands concerned in intestinal digestion secrete their juices and pour them into the small intestine. When the chyme passes through the pylorus into the duodenum, digestive juices are there ready to receive it.

These are the pancreatic juice, the bile, and the secretions from the small glands embedded in the mucous coat of the intestine.

These, when mingled with the food mass, change the acid chyme to the alkaline *chyle*.

Action of the pancreatic juice.—The secretion of the pancreas is the most important of the intestinal juices. It is a clear, alkaline liquid, and is capable of doing three things: First, it rapidly converts starch into sugar. This action was begun by the saliva, but was stopped by the acid in the gastric juice of the stomach.

Second, it digests any proteids that escaped digestion in the stomach.

Third, it changes some of the fats to soap, in which form it is soluble in water, and so can be absorbed. Most of the fats, however, are only emulsified, and are passed as small droplets through the bodies of the epithelial cells.

The action of bile.—The human bile is a brownish liquid, but will, if kept for a time, turn green. Its use is not fully known, but it is certain, from the bad effects which follow when the supply is shut off, that bile has an important office in digestion.

It is alkaline, and helps to neutralize the acid of the chyme. It excites the muscular coat to action, and thus is a means of moving the food along the intestine.

It also facilitates the absorption of fats.

Intestinal juice.—The juice secreted by glands in the mucous coat of the intestine is, like the other two, alkaline. It converts the sugars which we eat into a kind which can be more readily absorbed by the villi.

The large intestine.—The final portion of the alimentary tract is called the *large intestine.* It is but five feet in length, but is called "large" because it will average about two inches in diameter. The area of its cross-section, then, is nearly four times as great as that of the small intestine.

It begins on the right side of the abdomen and extends up along that side, forming the *ascending colon;* then across, forming the *transverse colon;* then down on the left side, forming the *descending colon.* (See Fig. 53.)

The small intestine opens into the side of the colon some distance from the end. At this opening there are folds of the mucous membrane which form a valve called the *ileocolic valve.* By this arrangement the contents of the small intestine may easily pass into the colon, but cannot return.

The part of the colon below the ileocolic valve is called the *cæcum* (blind), because it is closed at the lower end. From the cæcum hangs the vermiform appendix. This is a slender tube about four inches long, and is the seat of a common inflammation called *appendicitis.*

The coats of the large intestine are the same as in the small, except that the mucous coat is not supplied with villi. It is furnished, however, with numerous glands.

Action of the large intestine.—By the time the food mass has reached the ileocolic valve its valuable food contents have been largely absorbed. That which enters the colon is mostly water, some food, and waste products. In the large intestine a great deal of water is absorbed, and the digestion of the remnants of food will continue and the food will be absorbed.

The residue is cast from the body.

Hygiene of Nutrition. Mastication.—Thorough mastication is a matter of real importance in the preparation of the food for digestion. Foods must be chewed until they are thoroughly ground up. Experiments show that those who insist on thorough mastication have fewer ailments of their digestive organs and are stronger with a less quantity of food.

Even when food is quite soft, it is necessary to chew it until it is well mixed with saliva, for the ferment in saliva continues its effect on starch throughout the digestive tract, except in the acid contents of the stomach.

Care of teeth.—Mastication will not be well done unless the teeth are good. Teeth will readily decay. Particles of foreign matter allowed to remain between the teeth is the cause of much of the decay.

After each meal a wooden toothpick should be used, and the teeth washed with brush and water. Since the material of the teeth is chiefly phosphate of lime, acid will dissolve them. For this reason it is well to use often a mild soap in washing the teeth to neutralize any acid.

Teeth which are neglected are apt to become covered with a coating called *tartar*. This is not only injurious to the teeth, but objectionable in appearance, and should be removed by a dentist.

Decay begins at a small spot on a tooth and extends in to the pulp. The beginning of decay may escape attention for a long time, and after toothache begins it is often too late to save the tooth.

It is a good plan to consult a dentist two or three times a year, if only to be assured that the teeth are in a sound condition.

A healthy stomach.—As long as the stomach is in a healthy state one is seldom conscious that he has such an organ. When it is disordered, however, it is the cause of a great deal of suffering, and the whole body must suffer with it.

Some practices which produce a disordered condition of the stomach, and which are to be avoided, are: (1) Eating too much; (2) forcing food into the stomach before it is properly masticated; (3) eating too often, thus keeping the stomach constantly excited to action without periods of rest; (4) doing vigorous work either directly before or after a meal; (5) the use of alcoholic drinks.

When proper care is taken with respect to gastric digestion, the proper conditions for the best intestinal digestion will be provided at the same time.

Alcohol and digestion.—It was once customary to take at meals some drink containing alcohol. Some people still continue the custom. It was supposed to aid digestion, but tests made in recent years show that it retards rather than promotes digestion. Food will remain longer in the stomach when alcohol is taken with it. Many drinkers are troubled with catarrh of the stomach. The mucous membrane becomes inflamed and unhealthy. The freedom from pain which the dyspeptic experiences after a drink of alcoholic liquor is not a result of the curative power of the alcohol, but of its deadening effect upon the sensory nerves.

The strong appetite which some have for strong drink is an indication of a disordered condition of the stomach. Appetite for bread is satisfied whenever enough is eaten, but that for alcohol may increase even beyond the control of the drinker.

QUESTIONS FOR REVIEW.

1. What is digestion? Illustrate.
2. Why is digestion necessary?
3. Describe an experiment showing the action in osmosis.
4. Have *you* tried the experiment?
5. How do fats get into the blood?
6. When food is in the stomach, is it inside or outside the body? Explain.
7. What are the parts of the alimentary tract?
8. What are the first two acts of digestion?
9. Describe the temporary set of teeth.
10. Classify the permanent teeth.
11. What is the crown of a tooth? Name the other parts.
12. What three parts are observed in a cross-section of a tooth?
13. Describe the enamel. The pulp. The dentine.
14. How is saliva secreted?
15. What is a racemose gland?

16. What are four uses of saliva?
17. What is ptyalin?
18. What makes saliva "ropy"?
19. Bound the fauces.
20. What is the uvula? What are tonsils?
21. What is the pharynx? Name the openings from it.
22. What is the epiglottis? What is its use?
23. What is deglutition?
24. Describe the œsophagus.
25. Locate and describe the stomach.
26. Describe the muscular coats of the stomach.
27. How is the stomach held in place?
28. Describe the mucous coat of the stomach.
29. What are the digestive juices of the stomach? What is the action of each?
30. What kind of food is digested in the stomach?
31. What changes are made on fats in the stomach?
32. What is the use of the muscular coats on the stomach?
33. What is chyme?
34. Describe the small intestine. Name its parts.
35. What is the mesentery?
36. What are valvulæ conniventes? What their use?
37. What is a villus?
38. Describe the structure of a villus.
39. Describe the liver. What part does it have in digestion?
40. Describe a liver lobule.
41. Describe the pancreas.
42. What three juices act upon the food in the small intestine?
43. What is the effect of the pancreatic juice?
44. What is the use of the bile?
45. Describe the large intestine.
46. What is the use of the ileocolic valve?
47. Describe the vermiform appendix.
48. What is the cæcum?

49. Describe the coats of the colon.
50. What are the changes on the food in the colon?
51. Why is thorough mastication necessary?
52. What causes teeth to decay?
53. What are some ways of caring for the teeth?
54. State several ways by which the stomach may be disordered.
55. What effect does cheerfulness at the table have on digestion?
56. What effect does alcohol have on digestion?
57. Will alcohol cure the cause of pain?
58. Why does appetite for alcohol become so strong?
59. What is a beverage? (See English dictionary.)

EXPERIMENTS.

To illustrate action of gastric juice.—Prepare an artificial gastric juice by mixing together *pepsin* 5 parts, hydrochloric acid 3 parts, and water 500 parts. Put into this liquid some pieces of hard-boiled egg, and keep at about the same temperature as the body. After a time the egg will be dissolved, or digested. This illustrates digestion of proteids.

Action of saliva.—Collect one-half test-tube full of saliva from the mouth. Put into it a little cooked starch and keep warm. In a short time make a test for sugar as follows:

Add to the contents of the tube a few drops of dilute copper sulphate. Then add caustic soda in excess until the liquid becomes a clear blue. Now boil the liquid in the upper part of the tube, and if grape sugar be present it will turn red.

Emulsion of fats.—Shake up some olive oil and a solution of caustic soda. The mixture becomes milky in appearance. The oil is divided into very fine drops, which do not collect together. This is called an emulsion.

CHAPTER IX

WHOLESOME AND UNWHOLESOME DRINKS

Much of the ill-health of the human race comes from not knowing what is good and what is not good for the body. Untold suffering has thus resulted from ignorance concerning the nature and effects of alcoholic drinks. Many false suppositions concerning their origin have led to mistaken ideas of their value. It is very important that such false opinions should be corrected.

It is well known that ripe fruit in its season is a wholesome part of a healthy person's diet; but the fruit season in the temperate zone is short, hence men have tried various means of preserving fruits beyond their ripening time. Drying is an old method of preserving fruit. In drying, the water of the fruit evaporates, and, if care is taken, the fruit is otherwise not much changed.

Another way of preserving fruit is to boil it with sugar and seal it while boiling hot in air-tight cans. If this is well done, the fruit does not lose its wholesomeness. But if the cans are not perfectly tight, or the fruit not sufficiently heated, germs of mould or other minute organisms get inside and cause the fruit to spoil. When this happens the fruit becomes unfit to eat, because the fermentation has changed its nature. It is apt to contain poisons which may cause illness if it is eaten.

Sometimes people wish to preserve only the juice of fruit and use it as a drink. If the juice is pressed out and at once heated and sealed in air-tight cans or bottles, while boiling hot, it can be kept from changing, just as fruit can by canning. If the juice is not thus heated and bottled, but is allowed to stand after it is pressed out, it will soon ferment and change. During the fermentation a poison is developed which makes the fermented liquid unhealthful.

The cause of fermentation in expressed fruit juice is a small germ, invisible except under a microscope; but it is not the same kind of a germ that causes whole or stewed fruit to spoil. The germ that sets up fermentation in expressed fruit juice is a species of yeast. Similar germs can be seen in common yeast by soaking it and examining it under a microscope. The wild yeast germs float in the air, in a dry state, settle upon the skins and stems of fruit, and from there are washed into the juice when it is expressed from the fruit. In a few hours, under the right conditions of moderate warmth, they begin to change the fruit juice. This change is called alcoholic fermentation, because the sugar of the fruit juice is thereby changed, in whole or in part, to alcohol and carbon dioxide gas. Every fermentation changes the nature of the substance fermented.

Fermented fruit juices are unhealthful, because they contain alcohol, which is a poison to the human system.

A poison is any substance whose nature it is when absorbed into the blood to injure health or destroy life. It is not necessary that a substance cause sickness or death at once, in order to be a poison; its injurious effects may follow so slowly and subtly that they do not show plainly at first.

Poisons are classified by authorities on this subject according to their characteristic effects upon the body, or its various parts. A narcotic poison is one that dulls or deadens the brain. Alcohol is classed by writers on poisons among the narcotics, because its most important effect is to dull the nervous system. It is similar in this respect to opium, ether, and chloroform, all of which belong to the same class, *i.e.*, narcotic poisons.

The most common drinks made in this country by fermenting fruit juices are cider, made from the juice of apples, and wine, made usually from the juice of grapes, occasionally from currants, elderberries, and some other fruits.

Wine has been much used as a promoter of social intercourse. The narcotic effect of the alcohol in the wine, when only a small quantity is taken, dulls the nerves enough to take the edge off of the understanding and weaken the self-control. In this condition a person says and does things which he would be ashamed of in his right senses. A company, after the effect of wine begins to show itself, will laugh at silly speeches which at other times would seem pitiable instead of funny. It is a poor compliment to civilization to assume that people must be slightly narcotized before they can be agreeable companions.

One danger in social wine drinking, in some classes of society, is that wine has been used as a means of administering drugs, which still further stupefy the mind and thus quickly prepare the way for crime. But the greatest danger in wine is the power of the alcohol it contains to make the drinker want more, while it destroys the power of his will to control the desire for more. It is futile to urge self-control in the use of a substance whose nature it is to destroy self-control. The best way of exercising self-control in regard to alcoholic drinks is to refuse the invitation to take them. The wine drinker may intend to be moderate; but it is the nature of the alcohol in his wine to weaken his self-control and make him immoderate.

Light wines, such as are ordinarily used as beverages, contain 10 per cent. of alcohol, but more is often added to wines till it may reach as much as 35 per cent.

Cider or fermented apple juice. The juice of apples when pressed out and fermented makes a liquid called cider. The yeast germs which are on the surface of the apples when they are ground and crushed grow and multiply so rapidly in the expressed juice that in a few hours much of the sugar of the juice may be changed to alcohol.

Cider-making is a common way of disposing of small and unsound apples; but it has been a sad economy for many farmers whose promising sons have acquired at the cider-barrel the craving for alcohol that has led to their destruction. Hard cider contains more alcohol than most malt liquors. When alcoholic fermentation has gone on until about 14 per cent. of the fermenting liquid is alcohol, the yeast germs can no longer continue their work. Another fermentation, however, the acetic, takes place in this liquid and changes the alcohol to acetic acid, by which process hard cider is turned into vinegar.

Beer.—A large percentage of alcoholic liquors is made from grain. These are the malt liquors, such as beer, ale, and porter, which may contain from 2 or 3 to 10 per cent. of alcohol. The most common of these is beer.

One of the principal food elements in grain is starch. When grains are ground and made into flour or meal, and then into bread or other cereal food, the starch remains largely unchanged, except such parts as are turned into dextrine, which is a kind of sugar and a good food. When grain is used for making beer, the starch is first changed to sugar by sprouting the grain, and the sugar is then soaked out with water. Thus is obtained a sweet liquid called wort, the sugar of which can be changed to alcohol by fermentation. Yeast is added to the wort. Alcoholic fermentation takes place and changes the sugar of the wort to alcohol, and the result is beer.

Beer, like all alcoholic liquors, is a dangerous drink because it contains alcohol.

The false idea that beer is harmless because there is not much alcohol in it and that a little will not do a man any harm, is a cause of much mischief. It makes the drinker careless about the amount he drinks. Even if he takes but little, that little has the power to set up a craving for more that leads him to make up for the weakness of his drink by the quantity he takes. Thus the beer drinker often gets as much alcohol as if he took whiskey or brandy.

The narcotic effect of the alcohol further deadens the drinker's sensibilities, making him careless, not only about his own welfare but that of others. Judges in criminal courts have again and again called attention to the frequent association of beer drinking with the commission of crime. Their testimony strengthens the evidence that beer is a demoralizing drink.

At the present time there is special need that boys be warned against the offer of free beer. Accepting such offers may fasten upon them the craving for alcohol that will lead to their spending the most of their future earnings for beer or other alcoholic drink. The effort to teach a boy to drink beer is not made for the benefit of the boy, but to swell the number of beer customers. Such attempts to mortgage a boy's future money-earning power to drink are as inhuman as the bygone practice of slave-catching in Africa.

The distilled liquors, gin, whiskey, rum, brandy, contain more alcohol than the fermented drinks. Gin contains 38 per cent.; whiskey, 45 per cent.; rum, 48 per cent.; brandy, 50 per cent. These are all injurious in proportion to the amount of alcohol they contain.

Drinking water.—It is of the utmost importance to the health of the people in any community that only good drinking water be used. Water is the only drink needed by man, and he should have plenty of it and have it free from impurities. A man needs about three quarts of water every day. A part of this is already in the foods eaten, so that a pint or more of water as such may satisfy the body's needs. There is very little danger that any one will drink too much pure water. A great deal is needed for proper digestion, absorption, secretion, and excretion. If water is drunk in excess, it is easily eliminated. Most people drink too little water. It should not be taken, however, to moisten the food in the mouth during a meal. The saliva alone must do that.

Sources of water.—All land water comes from rain. Part of it remains on the surface in rivers, brooks, pools, and cisterns, and is called surface water.

Part runs down through the ground and rocks, thus supplying the springs and deep wells. Another part is just beneath the surface and supplies the shallow wells.

Impurities in water.—Water is nature's great solvent, and also a universal culture medium for all kinds of minute organic life. While it slowly percolates through the soil and rock, it takes up in solution many mineral substances. These in a moderate quantity are not objectionable. Such water is found in most deep wells and springs.

Surface water *may* be good for drinking, but it is always to be suspected.

The rain falling upon the land carries to the streams any decaying matter which may be washed along, and the sewage of a city, if allowed to empty into a stream, may contaminate the water with germs of disease.

Water is safe only when free from decaying matter. Shallow wells are the greatest source of impure water. Decaying matter from barn-yards or out-houses may easily have a shallow underground passage to the well.

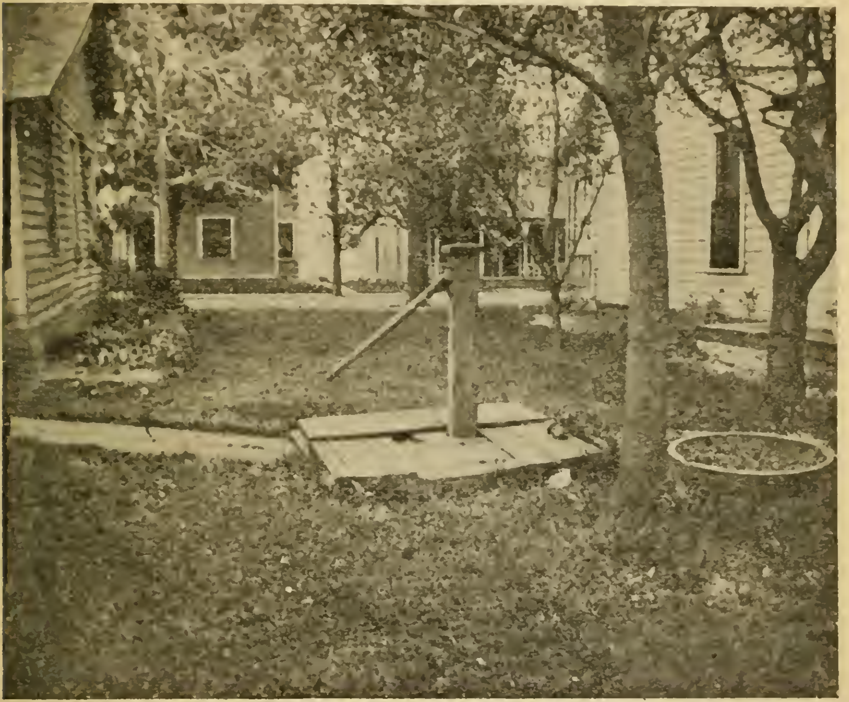


FIG. 60.—A shallow well, such as are always to be suspected.

Such wells have often started an epidemic of typhoid fever. A painted pump and neat lawn and curb about such a well do not purify the water, for the poison is seeping in beneath the surface.

A well deep down into the rock, with water-tight iron casing, will, as a rule, contain good water.

Means of purifying water.—Good water will be without color, odor, or organic matter of any kind. Effort is often made to provide such water by the use of small house-filters. These may make the water clear, but may not take out the germs of disease which are the most objectionable. In fact, an old filter often contaminates more water than it ever purified.

Nature's way is to filter water through thick layers of clean sand, gravel, earth, and rock, thus supplying the deep wells with pure water. This cannot be done for shallow wells, nor can man imitate this method on a small scale.

Organic matter in water may not of itself be injurious, but may be a food for certain classes of germs which then grow and thrive there.

If water is suspected, it should be boiled (not warmed) for twenty minutes. This will effectually destroy all bacterial life and make the water free at least from that danger.

Ice water.—The custom of placing ice in the water to be drunk is a wrong practice for two reasons.

First, if the water was impure from which the ice was taken, the ice will be impure. Germs of disease in water are not killed by freezing the water.

Second, much water at such a temperature interferes with digestion and may produce a disordered condition of the stomach.

Water may be cooled by ice, but the melted ice should never form part of the drinking water.

QUESTIONS FOR REVIEW.

1. How may fruit be preserved?
2. What is the cause of fermentation?
3. Why are fermented fruit juices unhealthful?
4. What is a poison?
5. What kind of a poison is alcohol?
6. State some evil effects of wine drinking.
7. How does the juice in the apple differ from hard cider?
8. How is beer made?
9. State some of the evil effects of beer drinking.
10. What are distilled liquors?
11. How much water does a man need in a day?
12. What is the effect of drinking more water than is needed?
13. Why should water not be taken along with foods?
14. What becomes of the water which falls as rain?
15. What causes water to be "hard"?
16. Why is rain water "soft"?
17. What is the source of impurities in water?
18. When is drinking-water safe?
19. Explain how shallow wells are liable to contain impure water.
20. Why is a deep well better?
21. What is the use of filters?
22. How may impure water be made fit to drink?
23. State some evil results that may follow the use of ice water.

CHAPTER X

CIRCULATION

Why circulation is necessary.—We have seen that the body is made up of a great many cells, each having a life of its own, but all working together to serve the purpose of the body as a whole. All the cells, however, except the white corpuscle, are fixed in position and incapable of moving from their place.

The cells cannot live without food, but they cannot go after it. *Circulation of the fluid food is necessary to carry nourishment to the cells.*

The cell cannot perform its functions without producing waste products, which must be carried away. *Circulation is necessary to carry off waste products and other objectionable substances, and transport them to organs of excretion, such as the lungs, liver, kidneys, and skin, where they may be taken out of the circulating fluid and cast from the body.*

How the food gets into the stream of blood.—Under the subject of digestion the food was followed until it was in a liquid form and had passed through the walls of the villi into the vessels within.

At this point was found a net-work of fine tubes. These are a part of the general circulating system, and here the food is taken into the stream of blood. Part of the tubes gather up all the food, except the fats, and convey it to the liver. Other tubes, called lacteals, collect the fats and convey them up through a tube called the *thoracic duct* to a vein in the left shoulder, whence it soon reaches the heart.

The blood that was carried from the stomach and intestines to the liver was there changed and purified by the action of the hepatic cells, and thus made fit to be sent out to the other cells of the body.

The proteid food, as has been explained, was changed by digestion to peptone so that it would dialyze through to the blood-vessels in the villi. In this form it would be a poison to the body, and must be changed back to proteid again. This is done by the epithelial cells that cover the villi, so that peptone in a healthy body does not get into the circulation.

Action of the liver.—The structure of the liver and its office in the secretion of bile has been described on page 108. It would seem strange, however, that such a large gland should have nothing to do but to secrete bile. It appears that the liver has another duty of much greater importance. Its chief work is to store up *glycogen* and deal it out to the current of blood as it is needed.

Glycogen is a kind of sugar which the liver is able to make from the sugars that are eaten and the starch which was converted to sugar in digestion. The quantity of glycogen in the liver is greatest just after the digestion of a meal and decreases during starvation until none remains. Thus the liver acts as a storehouse of this important food.

The liver is also a door-keeper guarding the entrance of food into the circulation, and, within the limit of its ability, will take out substances that would be harmful to the system.

After food passes the liver it is carried by a large vein to the heart.

The organs of circulation.—The circulation of the blood is accomplished by means of the *heart*, *arteries*, *capillaries*, *veins*, and *lymphatics*. The heart is the central organ of the system, and from it pass tubes, through some of which blood is sent out. and through others blood is received back again to the heart.

The whole system of tubes through which the blood circulates is closed except at two points, where the lymphatic ducts enter the subclavian veins,—one on each side under the clavicle. These two points are guarded by valves which close whenever blood would flow out into the ducts.

There is no place, then, where the blood can flow out of its channel to other tissues, except in the spleen (see spleen), and so the food can get to the cells only by oozing through the walls of the blood-vessels.

This occurs *only in the capillaries*. The purpose of the heart, arteries, and veins is to keep the capillaries supplied with a fresh current of blood.

The heart.—The heart is a large hollow bundle of muscular fibres. It weighs ten or twelve ounces. It is located in the thorax just above the diaphragm, and midway between the right and left sides. It is conical in shape, with its point downward, forward, and to the left. The base of the heart would then be towards the right shoulder.

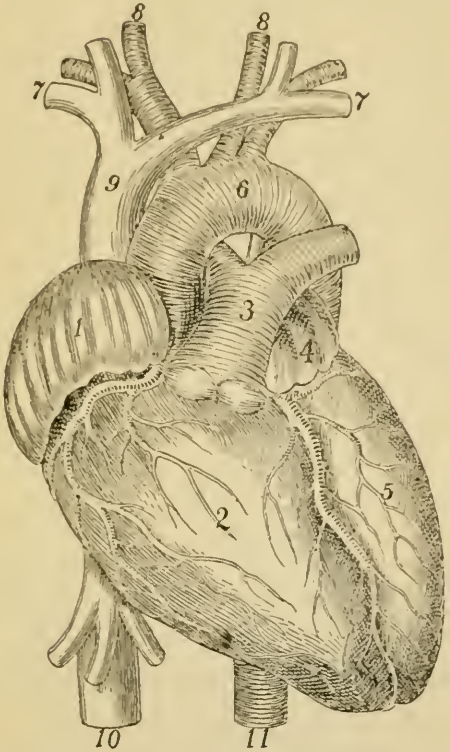


FIG. 61.—External view of the heart. 1, right auricle; 2, right ventricle; 3, pulmonary artery; 4, left auricle; 5, left ventricle; 6, aorta; 7, subclavian veins; 8, carotid arteries; 9, superior vena cava; 10, inferior vena cava; 11, descending aorta.

It is enclosed in a loose bag, which is attached to the diaphragm. The bag, called the *pericardium*, is lined with a moist and very smooth serous coat, so that there is very little friction between it and the heart proper.

The cavities of the heart are also lined with a coat called the endocardium.

Divisions of the heart.—The heart is double. The two halves are bound together, but have no opening between them. They are often called the *right* and *left hearts.* The only way blood can get from one side of the heart to the other is by going out in a circuit through the arteries, capillaries, and veins, and then back to the other side.

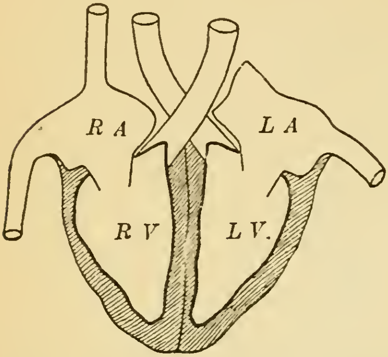


FIG. 62—Diagram showing cavities of the heart. *RA*, right auricle; *RV*, right ventricle; *LA*, left auricle; *LV*, left ventricle.

Each side of the heart contains two cavities. The upper ones are called *auricles* and the lower ones *ventricles.* So there is a *right auricle* and a *right ventricle* and a *left auricle* and *left ventricle.*

The left side of the heart is larger and stronger than the right.

The muscular walls of the left ventricle are thick and strong because they have the most of the heart's work to do,—that of forcing blood out to even the farthest extremity of the body.

Valves of the heart.—When the muscular walls of the heart contract they will make the cavity smaller and the blood will be forced out. There would be no advantage in this if the blood could go back through the same tube in which it entered; so valves are needed to

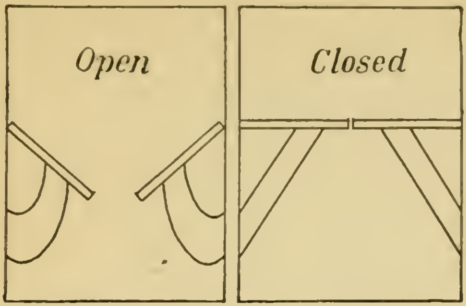


FIG. 63.—Diagram illustrating the action of the auriculo-ventricular valves.

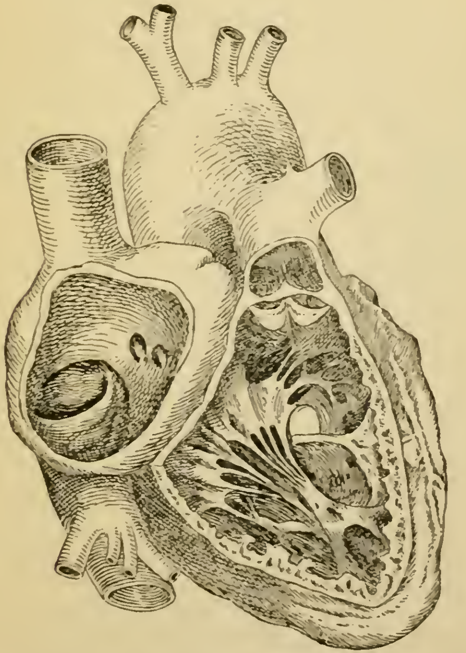


FIG. 64.—Section of the right auricle and right ventricle of the heart.

keep the blood always flowing in the same direction. Between the auricles and ventricles are valves having the common name *auriculo-ventricular valves.* The one between the right auricle and ventricle is called the *tricuspid valve*, while the corresponding one in the left heart is called the *mitral valve.* These valves are simply flaps of the endocardium, the tricuspid having three flaps or cusps, as the name indicates, and the mitral, two. These offer no resistance to blood flowing from the auricles into the ventricles, but any attempt of blood to flow in the opposite direction would push one flap against the other and thus close the opening.

Strong cords of connective tissue are fastened to the edge of the flaps and to the walls of the ventricle. These permit the valves to close, but prevent their going any farther. The arrangement is similar to that of double swinging doors which open in only one direction.

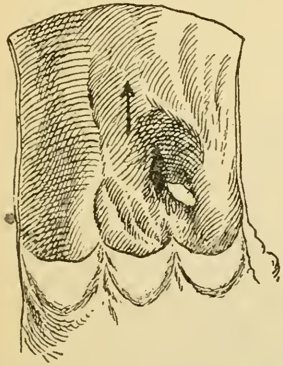


Fig. 65. – Semilunar valves.

At the point where the blood is forced from the left ventricle into the large artery, called the *aorta*, are three *semilunar valves.* They get their name from their half-moon shape, as seen in Fig. 65. They open to blood flowing out, but are closed by any movement of blood in the opposite direction.

The same arrangement is found at the point where blood is driven from the right ventricle into the artery leading to the lungs.

Course of the blood in the heart.—The blood enters the right auricle of the heart and flows on through the tricuspid valve into the right ventricle. When the right ventricle is filled its muscles contract and squeeze upon the blood, thus closing the tricuspid valve and forcing the blood through the semilunar valves, *m* (Fig. 66), into the artery, *S*, which leads to the lungs.

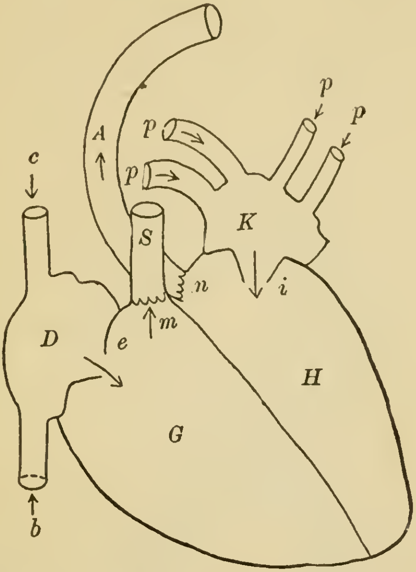


FIG. 66.—Diagram showing the course of the blood through the heart. *c*, superior vena cava; *b*, inferior vena cava; *D*, right auricle; *e*, tricuspid valve; *G* right ventricle; *m*, semilunar valve; *S*, pulmonary artery; *p*, *p*, *p*, *p*, pulmonary veins; *K*, left auricle; *H*, left ventricle; *n*, semilunar valve; *A*, aorta.

When the blood returns from the lungs it enters the auricle on the left side, *K*, and passes on into the left ventricle, *H*. The contraction of the strong muscles of the left ventricle closes the mitral valve, *i*, and forces the blood out into the great artery, *A*, which carries it to all parts of the system.

Thus the auricles act as reservoirs to hold the blood while the valves are closed, and the valves act like the valves of a pump, opening only to a flow in one direction.

The arteries.—*Arteries* are tubes through which blood is forced out to the various tissues of the body. The arteries stand open like a heavy rubber tube, whether they are filled with blood or not.

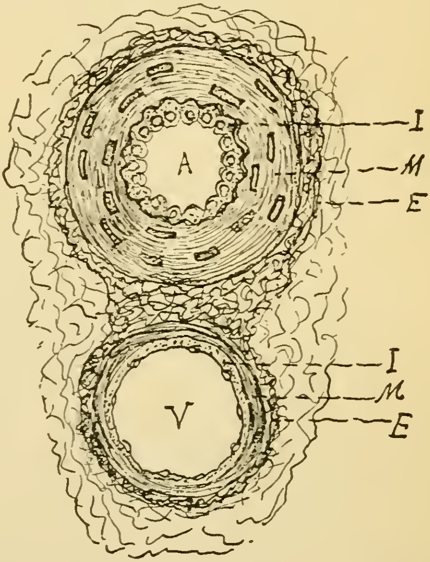


FIG. 67.—Section of artery and vein. *A*, artery; *V*, vein.

The walls of arteries are composed of three coats. The inner one is thin and transparent, being a continuation of the inner lining of the heart. The middle coat is quite thick in the larger arteries, and is composed of muscular fibres and yellow, elastic tissue arranged in rings around the tube. The outer coat is composed of layers of white, fibrous tissue, and so is very strong and tough.

Distribution of arteries.—The arteries arise from the heart, one from each ventricle.

The one from the right ventricle carries the impure blood to the lungs. It is called the *pulmonary artery.*

The one from the left ventricle carries the pure red blood out to all parts of the body. It is called the *aorta.*

The aorta arches up over the heart, sending off branches to the heart itself, the head, and the arms. Then it descends, close to the backbone, through the thorax, sending off numerous small branches to nourish the tissues in that region. Then it passes through the diaphragm into the abdomen, where many large branches are distributed to the important organs located there.

Near the base of the abdomen the aorta divides, one branch passing down each leg.

Each of these numerous branches also divides in a similar manner until the tubes are so small they cannot be traced except by the aid of a microscope. At the ends of the numerous fine arteries the capillaries begin.

Capillaries.—The *capillaries* are very fine tubes that pervade nearly every tissue of the body. They are interposed between the ends of an artery and the beginning of a vein.

The walls of the capillary tubes are an extension of only the thin inner layer of the artery, and so the food contents of the blood can easily transfuse to the cells just outside.

The average size of the capillaries is about $\frac{1}{1500}$ of an inch, but they lie so close together and are so numerous that it is hardly possible to prick the skin with a fine needle without puncturing some of them and letting out some blood.

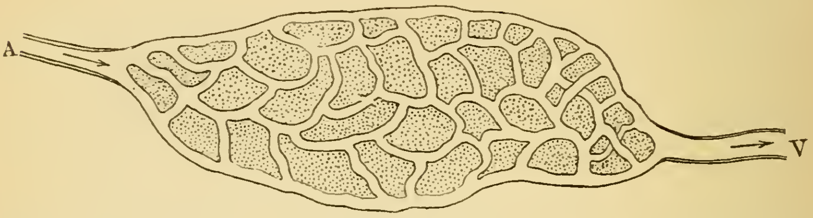


Fig. 68.—Capillaries. *A*, terminal of fine artery; *V*, origin of vein.

The capillaries are the most essential part of the whole system of circulation, for it is from them alone that the cells are fed. In Fig. 69 is a representation of the relation of the capillaries to a bundle of muscle-fibres.

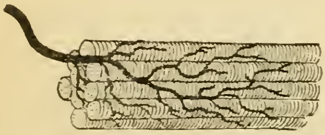


Fig. 69.—Diagram showing muscle-cells and blood capillaries.

The cells of the muscle are surrounded by a liquid called *lymph*. As the blood passes through the capillaries the cell-food transfuses through into the lymph. Both the cells and the capillaries are bathed in lymph, and the exchange takes place according to the principle of osmosis explained on page 95.

The cell then takes its food from the lymph.

Blood moves very slowly in the capillaries,—only about one inch in a minute,—and so there is time for the osmotic action.

Veins.—The arteries begin as a single large tube, which divides and subdivides until the branches are exceedingly numerous and minute, when they pass into the capillaries.

At the other end of each capillary is a minute vein which now receives the blood.

These fine veins unite to form a larger tube, which increases in size as it approaches the heart.

Thus the blood flows from the large artery out *to* its branches; while in a vein it starts at the branches and is *collected into a large vein.*

The arteries distribute blood, the veins collect it and bring it back to the heart again.

Two large veins return the blood from the system to the heart. One, called the *superior vena cava*, collects all blood from parts *above* the heart, and another, called the *inferior vena cava*, collects all blood from regions *below* the heart.

Structure of veins.—The walls of veins are composed of three coats similar in structure to those of arteries, but the middle one is not nearly so thick. Veins do not stand open except when filled with blood.

In the veins at intervals are placed semilunar, or half-moon, valves, at some points one, and at others two or three, together. They are pockets fastened to the walls of the vein so that blood may flow past them towards the heart; but if it flows in the opposite direction the pockets will fill with blood and press against each other, thus closing the vein. The semilunar valves of the heart operate in the same way. (See Fig. 65.)

Veins are slightly enlarged at the points where valves are placed. If the flow of blood in a surface vein be stopped by pressure, the position of the valves can be located by the "knots" seen here and there along the vein.

Lymphatics.—As explained above, the active tissue-cells are constantly bathed in lymph, which is constantly supplied from the blood. When the lymph has served its purpose it must be drained off. This, however, is not done by the veins, but by a special system of tubes called *lymphatics*. These begin as very small tubes which unite, forming two ducts that convey the lymph to the right and left subclavian veins.

The ducts are supplied with valves similar to those in veins.

The two ducts are called the *thoracic duct* and the *right lymphatic duct*.

The thoracic duct collects the lymph from the lower extremities, the abdominal organs, the left side of the head and thorax, and the left arm, and empties into the left subclavian vein.

The right lymphatic duct collects from the right side of the head and thorax and the right arm, emptying into the right subclavian vein.

The thoracic duct also receives the emulsified fats which were collected by the lacteals in the villi of the intestines.

Lymphatic nodes.—At many points along the lymphatic ducts are nodes or knots. They are numerous in the groins, neck, armpits, and mesentery. When for any reason they are inflamed, they are spoken of as "waxen kernels." They are made up of interlacing connective tissue packed with cells which are very much like white corpuscles.

The lymph filters through the nodes, carrying with it some of the cells, which become white corpuscles in the blood.

The spleen.—The *spleen* may be considered a large lymph-node. It lies just below the stomach on the left side. It is a dark red body about five inches long and weighs about six ounces. It is spongy in texture, and its meshes are filled in with a soft substance called *spleen-pulp*.

The pulp consists largely of red and white blood-corpuscles.

The blood brought by the splenic artery is poured directly into the spleen-pulp and comes directly in contact with the cells and tissues there.

The spleen appears to be concerned in the production of white corpuscles and in the elimination of worn-out red ones.

The exact function of the spleen is not yet fully known.

Blood.—Blood is a liquid which is composed of all the substances needed to nourish and maintain the life of the cells. It constitutes about one-thirteenth of the weight of the body.

Blood has three great duties to perform: (1) to carry to the cells of the body the food which is taken up from the alimentary canal; (2) to take oxygen from the air which we breathe and distribute it to the cells; (3) to gather up waste matter, such as *carbon dioxide*, *water*, and *urea*, and carry them to the excretory organs, where they are cast out.

Blood is composed of *blood-plasma*, *red corpuscles*, and *white corpuscles*.

Blood-plasma.—Blood-plasma is the purely liquid part of the blood. About 90 per cent. of it is water. In solution in the water are the proteids, which constitute about 8 or 9 per cent. of the plasma, and the carbohydrates, fats, and minerals, which form about 2 per cent.

In addition to these is a small quantity of another substance called fibrinogen, which causes blood to clot.

Red corpuscles.—After blood has passed through the capillaries of the lungs it has a bright red color. The only part of the blood having this color, however, is the red corpuscle.

Red corpuscles are very small, circular discs, which are concave on both sides. They are about $\frac{1}{3200}$ inch in diameter and one-fourth as thick. It has been calculated that there are 5,000,000 of them in a drop of blood as large as a pinhead. When only a few are seen they are faintly red, but a great number together give a deep-red color.

Fig. 71 shows the appearance of human blood when it is spread exceedingly thin under a compound microscope.

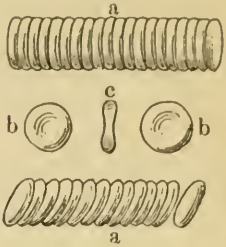


Fig. 70.—Red corpuscles. *a*, *a*, a number joined; *b*, *b*, side view; *c*, view of edge.

Hemoglobin.—The function of the red corpuscle is to carry oxygen out from the lungs to the tissues of the body. It is made up of a fine, spongy framework called the *stroma*, in the meshes of which is a substance called *hemoglobin.*

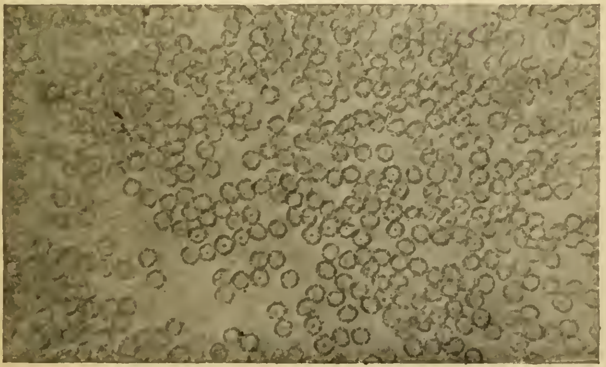


Fig. 71.—Blood seen under a microscope.

This substance is the most important part of the corpuscle. It is a proteid substance and contains iron. Its great value lies in the fact that it will readily combine with oxygen in the lungs, and then, floating in the plasma, will carry the oxygen out to the tissues and give it up to them.

The hemoglobin is red when it is oxidized, but as soon as it loses the oxygen it turns purple. Hence the difference in the color of blood before and after passing through the capillaries of tissues.

Origin of red corpuscles.—Red corpuscles perform their part for a certain length of time, and when worn out are brought, it is thought, to the spleen, where they are disintegrated. New ones must then be set afloat at some point in the body. This appears to be done in the red marrow of the bones, for at that place are found colored cells with a nucleus, and from them appear to come the unnucleated discs called the red corpuscles.

White corpuscles.—White corpuscles are masses of protoplasm with one or more nuclei. They are usually larger than red corpuscles, but are not nearly so numerous. When at rest they are spherical in form, but are capable of assuming a great variety of shapes, very much like the amœba described on page 21.

White corpuscles are carried along by the blood, but are not confined by the blood-vessels, for they can pass out through the walls into the tissues when necessary.

Function of white corpuscles.—White corpuscles move about in the blood and through the tissues of the body, apparently without anything to do, but always on the lookout for something to do.

They have been called the scavengers of the body, because if they meet any foreign substance they at once set about to remove it.

The foreign matter is taken into their own bodies and dissolved or carried out to the surface. This is often done at the sacrifice of their own lives to save the body.

When the skin or mucous lining is cut or broken, germs of disease will lodge there and begin to multiply and feed on the tissues. When this happens, the white corpuscles collect about the spot in great numbers and attack the invading germs.

In such a case the white corpuscles are like a standing army called upon to repel an invasion. If the army is strong, as it is in good health, it usually comes off victorious. Many of the corpuscles, however, must sacrifice themselves in the conflict, and the pus in a wound is a mass of their dead bodies.

Blood-clots.—While the blood is in the living body it is a thin liquid. But as soon as any is allowed to escape it becomes thick, and forms the blood-clot. After blood has stood for an hour or more the clot shrinks in size, and a yellow liquid called serum runs from it. Serum is just like plasma, except that the fibrinogen is wanting. (See page 142.)

The clotting is due to the fibrinogen, which, for some cause unknown, is changed into a great number of interlacing fibres called *fibrin*.

The threads of fibrin gradually contract and gather up, as in a net, all the corpuscles and squeeze out the serum. This operation is called *coagulation.*

Fibrin can easily be separated if some fresh blood, secured at the slaughter-house, be whipped with a bundle of twigs. The fibrin will adhere to the twigs, and can then be washed and examined.

The circuit of the blood.—After this study of the various organs of circulation and their function, we are ready to follow the blood in its circuit through the body.

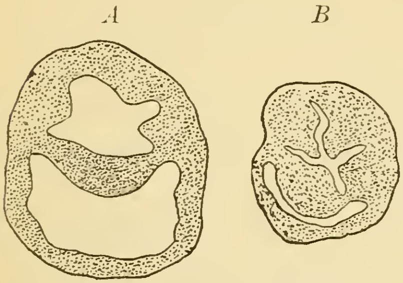


FIG. 72.—Section through the ventricles of the heart. *A*, when ventricles are filled with blood; *B*, just after contraction.

Since only pure blood is ready for distribution, and the left ventricle of the heart is the chief agent in sending it out, the proper place to begin the circuit is at the left ventricle of the heart.

This cavity, as we have learned, is surrounded by very heavy muscular walls capable of hard work. When filled with red blood, the muscle-fibres shorten, thus closing the cavity and forcing the blood out through the semilunar valves into the aorta. This great artery communicates by numerous branches to every tissue of the body.

In the arteries.—The walls of the arteries are composed in part of elastic tissue. The left ventricle forces a quantity of blood into them at every beat. Thus the arteries are kept so full that their elastic walls are stretched. We can now see the use of the semilunar valves to keep the blood in the aorta until the left ventricle can fill up again. The arteries thus exert a steady pressure upon the blood within them.

Pulse.—New blood is forced into the aorta, which is already full and distended. This causes a *wave* or *pulse* to pass over it. The pulse may be felt at any point where the artery comes close to the surface. Blood passes through the large arteries at the rate of about one foot per second ; but it is not the rush of blood that causes the pulse.

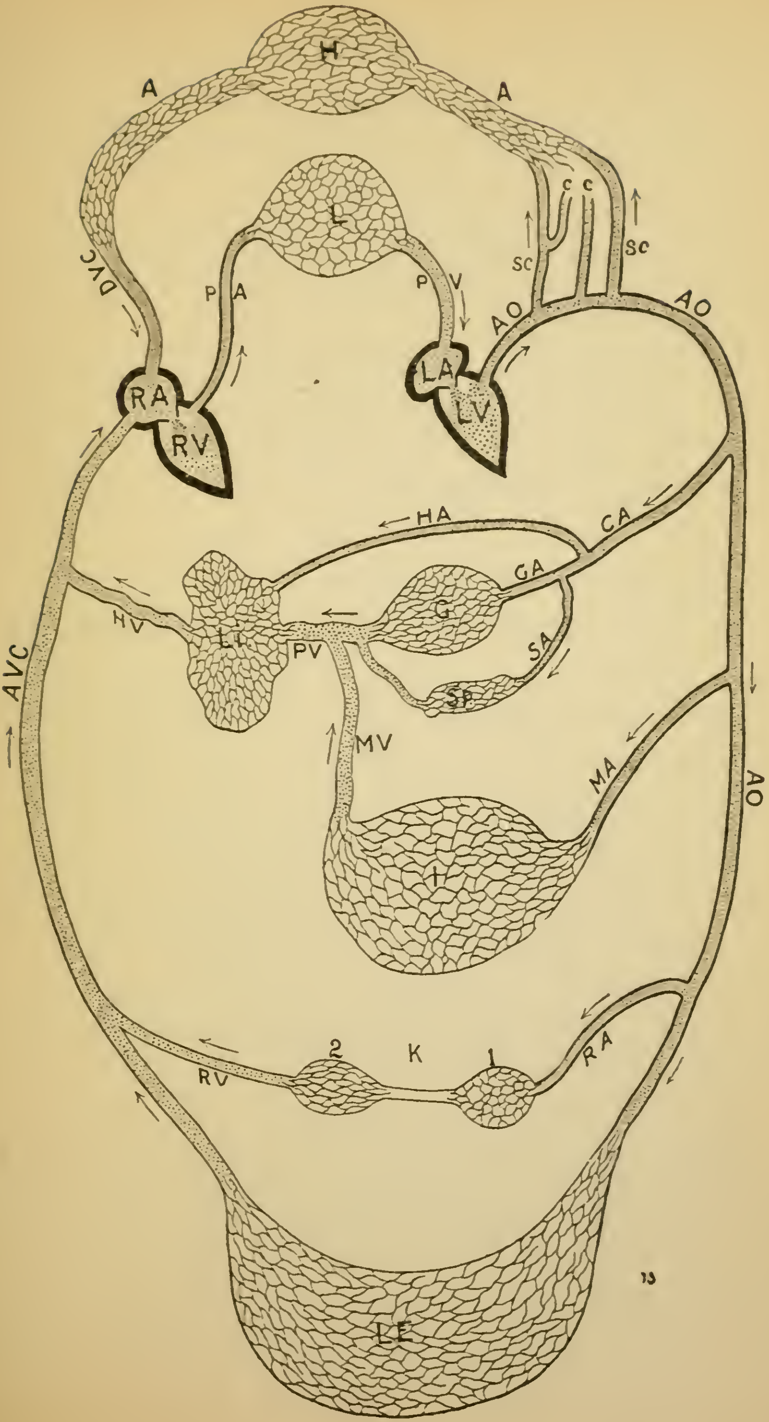
The fresh ventricle-full of blood causes a sudden enlargement of the aorta at the point where it enters, and it is this distention which travels as a wave, or pulse, along the artery.

Control of quantity of blood in an artery.—One of the coats of the wall of an artery is composed of muscular fibres which pass *around* the artery. When these contract they make the artery smaller, and when they relax they permit the elastic tissue to stretch, and the artery may become larger. In this way the quantity of blood which may flow to any part of the body can be regulated.

The action of these muscles is under the control of the *sympathetic nervous system*, as will be explained later.

The flow of blood is not under control of the will, but

Fig. 73.—Scheme showing the circulation of the blood. *RA*, right auricle; *RV*, right ventricle; *PA*, pulmonary artery; *L*, capillaries of lungs; *PV*, pulmonary vein; *LA*, left auricle; *LV*, left ventricle; *AO*, aorta; *Sc*, *Sc*, subclavian arteries; *c*, *c*, carotid arteries; *A*, *A*, capillaries of arms; *H*, capillaries of head; *CA*, cœliac artery; *HA*, hepatic artery; *SA*, splenic artery; *GA*, gastric artery; *G*, capillaries of stomach; *Sp*, capillaries of spleen; *PV*, portal vein; *Li*, capillaries of liver; *HV*, hepatic vein; *MA*, mesenteric artery; *I*, capillaries of intestines; *MV*, mesenteric vein; *RA*, renal artery; *K*, 1, capillaries of Malpighian bodies of the kidneys; *K*, 2, capillaries about the tubules of kidneys; *RV*, renal vein; *LE*, capillaries of lower extremities; *AVC*, ascending vena cava; *DVC*, descending vena cava.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73

certain kinds of emotion may result in such a contraction of the arteries carrying blood to the head that the face may become very pale, and fainting may result from lack of blood.

Other kinds of emotion may cause the muscles to relax and a large quantity of blood will come to the face, causing *blushing*.

Exposure to cold will cause the arteries near the surface to contract, and so the skin becomes white. Warmth will relax them, and a ruddy color comes with an increased supply of blood.

Blood in the capillaries.—The arteries have divided into countless small branches, and the blood in a steady stream. and without any pulse, now leaves them and enters the capillaries. Here the exchange takes place between the blood and the tissues. The nature of the exchange will depend on the contents of the blood and the nature of the tissue through which the capillaries pass. In the liver one kind of exchange will occur; in the kidneys, another kind; in the villi, the lungs, the muscle, the bone, and the skin, still other kinds. In all cases, however, the exchange occurs through the walls of capillaries.

Systems of circulation.—There is but one great system of circulation, for the blood which leaves the left ventricle of the heart will return to the same point again.

For convenience, however, the circuit may be divided into several systems depending on certain marked changes effected in the blood at various points in its circuit.

The most important divisions are the *systemic*, the *portal*, the *renal*, and the *pulmonary*.

Systemic circulation.—Blood is supplied by the arteries to the cells of every tissue of the body. This is the *general* or *systemic circulation*. By this system blood is carried to the capillaries about the cells of muscle, bone, nerve, and all other tissues. In these capillaries the blood loses the materials needed for the repair and growth of the cell, and for energy. These pass by osmosis into the lymph about the cell. At the same time the blood gains, by osmosis *into* the capillaries, *carbon dioxide*, *water*, and *urea*.

Distinction must be made between the systemic circulation, where blood is supplied *for the benefit of the cells*, and the other kinds of circulation, where blood is forced through capillaries of various organs that it may be modified or purified. All these latter changes are for the benefit of the systemic circulation.

The portal circulation.—The blood which is furnished by the systemic circulation to the stomach, intestines, pancreas, and spleen supplies the needs of the cells of those organs, and also furnishes materials needed for the juices used in digestion. In exchange for these, the blood takes up a supply of food which has passed from the digestive tract into the capillaries of the stomach and intestines.

The blood is now gathered up from these four organs by minute veins which unite into one large one called the *portal vein.* Through it this blood is conducted to the liver, where it passes through a second set of capillaries and is changed in a manner explained on page 129.

This is the only place in the body where a vein supplies blood to capillaries.

Renal circulation.—Two branches of the abdominal aorta carry blood to the kidneys. Some small branches of these are made to supply blood to the tissues of the kidneys, but most of the blood passes through another system of bodies, to be described later. The blood here loses a great deal of water and urea. Just after the blood passes through the kidneys it is probably purer than at any other point in its circuit.

In the veins.—After any portion of blood has fulfilled its purpose in circulation, it is gathered up and brought back to the heart by the regular system of veins. The color of the blood is now a purple, because that is the color of hemoglobin when it loses its oxygen.

Pulmonary circulation.—Although the blood has returned to the heart, it is by no means back to our starting-place at the left ventricle. It has only reached the right heart.

The *superior* and *inferior vena cava* now pour the blood into the right auricle, whence it flows into the right ventricle. The walls of the right ventricle now close in upon it, shutting the tricuspid valve and forcing it out into the *pulmonary artery* and on to the lungs.

When the blood started out from the left ventricle it was a bright red, showing that the red corpuscles were loaded with oxygen. When it passed through the capillaries of the systemic system the oxygen was given up to the cells there, and the color of the corpuscles changed to purple.

The pulmonary artery is the only artery that carries purple blood.

In the lungs an important exchange is made. Blood gives up carbon dioxide, water, and certain organic impurities to the air in the air-sacs, and takes in return a fresh supply of oxygen.

The blood is now a bright red again and is conducted by the pulmonary veins to the left auricle. Thence it flows into the left ventricle. The circuit is now complete.

Heart-beats.—The two auricles contract and relax together. Likewise the two ventricles. While the ventricles are contracting the auricles are filling, and as soon as the ventricles relax the auricles contract.

As explained before, the auricles are hardly more than small reservoirs to hold blood while the valves below them are closed. Their contraction is but feeble.

The alternate contraction and relaxation of the ventricles may be felt at a point where the apex of the heart is close to the chest-wall. This point is to the left of the sternum, between the fifth and sixth ribs.

Sounds of the heart.—If the ear be pressed tightly upon the point directly over the apex of the heart, two distinct sounds are heard during each beat. They are similar to the sounds made in pronouncing the syllables *loob dŭp.* The sounds are caused by the action of the valves. The mitral and tricuspid valves close at the same time, producing the sound *loob.* When the ventricles relax, the back pressure of the elastic aorta suddenly closes the semilunar valves, causing the sound *dŭp.*

Work of the heart.—The heart of an adult beats about seventy-two times every minute. The ventricles have to force the blood into the arteries against a strong back pressure, and they must continue to do this about seventy-two times a minute during life.

As a consequence the heart is the hardest-worked organ in the body. If a strong man would carry upon his shoulder a weight of 200 pounds to the top of a mountain 2000 feet high, he would have done no more work upon the weight than the heart does every day upon the blood.

Rest and nourishment of the heart.—After each contraction of the heart there is a period of relaxation and rest which is even longer than the time of contraction.

Thus the heart rests more than half the time, though each period of rest is short.

The muscles of the heart are well supplied with blood.

The first branch from the aorta, just above the heart, is the *coronary artery*, which carries blood directly to the muscles of the heart and supplies the cells with food. The heart gets no nourishment from the blood while it is in the auricles and ventricles.

Hygiene of circulation.—A *vigorous* circulation of *good* blood is sure to result in good health and a rapid recovery from temporary illness or accidental injury. But good blood is possible only under the four conditions already pointed out. (1) A plentiful supply of nourishing food must be taken into the blood-current from the alimentary tract. (2) The blood must be supplied with an abundance of oxygen from the air in the lungs. (3) The kidneys, liver, lungs, and other excretory organs must take from the blood the waste products and other substances no longer of use in the blood. (4) The nervous system must be able to control the flow of blood and to direct it to the point where it is most needed.

Effect of exercise on the circulation.—It is observed that exercise increases the rapidity of the heart-beats. This results in a more rapid flow of blood, deeper breathing, and, in time, hunger. Blood is supplied in larger quantity to any part of the body that is active. An exercise that calls into action every part of the body will quicken the flow of blood through the entire system. Such exercise frequently repeated tends to build up a stronger body.

Contraction of the muscles and movements of the body also assist circulation in a mechanical way. The veins and lymphatics are supplied with numerous valves, so that any pressure upon them will always push the liquid within them towards the heart, for the valves will prevent any movement in the opposite direction.

Since many veins and lymphatics lie near the surface, any tight bands or clothing will seriously impede the circulation at any time, but particularly during exercise.

Colds.—The cause of "colds" is not certainly known, but they appear to be closely connected in some way with the circulation of the blood.

An exposure to cold weather, to wet, or to drafts of air may contract the blood-vessels on the surface of the body and bring about a condition called a cold. Whatever may be the exact cause, it is known from experience that colds may be avoided by maintaining a vigorous circulation by exercise and deep breathing. Woolen clothing assists in preventing sudden changes in surface temperature.

Bleeding from a wound.—When a vein is punctured, the blood oozes out in a steady stream because it is not under pressure. The bleeding may be stopped by a bandage on the side of the wound farthest from the heart.

When an artery is severed, the blood issues in a stream with considerable force, which increases with each beat of the heart. Such a wound needs immediate attention.

The bleeding may be temporarily checked by a tight bandage on the side of the wound towards the heart. The bandage must be tight, as the arteries usually lie deep in the flesh.

Effect of alcohol on the heart.—Under some conditions the heart may beat faster after a person takes an alcoholic drink, but such quickened action is not due to any strengthening action of alcohol on the heart itself, as was once supposed. It is due rather to disturbance of the nerves in other parts of the body.

The mere act of swallowing or sipping cold water will increase the beating of the heart, and so will swallowing any hot, biting substance, as pepper or ginger tea, because of the sensitiveness and complex relations of the nervous system. When the heart beats faster after taking an alcoholic drink, the result is chiefly due to such disturbance of the nerves, for when care is taken to avoid all irritation of the throat and stomach in giving an alcoholic drink, little or no change in the heart-beat occurs. Muscular action also makes the heart beat faster, and so in all exact tests of this kind the person taking the alcohol is kept quiet and away from the company of others. Under such precautions it is seldom that any change in the heart's action occurs, showing that the old notion that alcohol is a stimulant or a source of strength for the heart is false.

Instead of being a benefit to the heart, alcoholic drinks are a fruitful source of heart disease. German physicians have begun to observe that in cities where the most beer is drunk they have the largest number of cases of heart disease.

Alcohol and the arteries.—It has been explained that the supply of blood through the arteries is regulated by muscles under control of the nervous system. A large dose of alcohol, such as is contained in a drink of whiskey, will disturb the controlling power of the nervous system and allow the arteries to relax, and warm blood flows freely out to the surface of the body.

Thus the heat can rapidly radiate and the temperature of the whole body is reduced.

For this reason those who drink alcoholic liquors suffer more and will be more quickly frozen from long exposure to cold.

Alcohol and oxygen.—The oxygen forms only a loose chemical combination with the hemoglobin of the red corpuscle. Alcohol has a strong affinity for oxygen, and. when mingled with the blood, robs the corpuscles of the oxygen which should go to the tissues.

While the oxidation of the alcohol will produce heat, it is at the expense of the bodily health and vigor.

Tobacco and the circulation.—Experience shows that the nicotine of tobacco is injurious to the organs of circulation. particularly to the heart.

The heart-beat often becomes irregular and spasmodic. It is claimed by reputable physicians that much of the heart-trouble and heart-failure is caused by the use of tobacco.

Tobacco is particularly harmful to youth under thirty years of age.

QUESTIONS FOR REVIEW.

1. Why is circulation necessary?
2. How does food get from the stomach and intestines into the blood?
3. What is the use of glycogen?
4. Give three functions of the liver.
5. Name the organs of circulation.
6. What is the heart? Its size, shape, and position.
7. Describe the pericardium.
8. Describe the cavities of the heart.
9. Name and locate the valves of the heart.
10. Make drawings to show the manner of action of the valves.
11. Make drawing and trace the course of the blood in the heart.
12. What are arteries? Describe their coats.
13. What is the function of the pulmonary artery?
14. Describe the course of the aorta.
15. What are capillaries? What does the word mean?
16. What is the location and size of capillaries?
17. What is the function of the capillaries?
18. How does food get from the capillaries to the cells?
19. How is the blood collected again?
20. Describe the structure of a vein.
21. What kind of valves in veins? How may their location be observed in surface veins?
22. What is the function of the lymphatics?
23. Describe the two large lymphatic ducts.
24. What are "waxen kernels"?
25. What is the construction of the lymphatic nodes? What their function?
26. Describe the spleen.
27. How much blood in a man who weighs 200 pounds?
28. State three important uses of blood.

29. What is the composition of blood?

30. Describe blood-plasma.

31. Give a full account of the red corpuscles.

32. What is the function of hemoglobin?

33. What is the origin of the red corpuscle?

34. Describe the white corpuscle. What is its origin?

35. Of what use is the white corpuscle?

35. What is fibrin? How is it formed?

37. Beginning at the left ventricle, trace the blood in a complete circuit through the body. (It will take some time to prepare and answer this question, but it should be done. The answer will include all matter from page 146 to 153, and should be prepared by each pupil for one continuous recitation.)

38. Explain the beating of the heart.

39. Describe the sounds of the heart.

40. How much work does the heart do?

41. What is the coronary artery?

42. What four conditions will supply good blood?

43. How does exercise affect circulation?

44. What is the effect of alcohol on circulation?

45. How does blood flow from a cut in an artery? How from a vein? Why?

46. What should be done when an artery is severed?

47. On which side of an artery must pressure be applied to stop bleeding? Why? How in case of a vein? Why?

EXPERIMENTS.

Fibrin.—Secure a quart of fresh blood at the slaughter-house. Take a stock of broom or a bundle of fine twigs and beat it in the manner of beating eggs. The fibrin will cling to the broom, and the red corpuscles adhering to it can be rinsed off with water. After the fibrin is taken out, the remaining part will not coagulate, however long it may stand.

Serum.—Allow some fresh blood to stand for a time in a glass jar. A clot will form in the centre. and a yellowish liquid, the serum, will separate from it.

To show the pulse at the wrist.—Secure a small piece of mirror about $\frac{1}{4}$ inch square, and fasten it with wax onto the point in the wrist where the pulse is most plainly felt. Rest the hand near a window in such position that the sunlight will be reflected to the ceiling of the room. At every beat of the heart the bright spot on the ceiling will move back and forth through a foot or more.

To illustrate the principle of the pulse.—Connect one end of a heavy rubber tube to a water-tap. Turn the water on, and then close the other end of the tube until water issues in a small stream under pressure. The tube will be stretched and rigid like a large artery. Now suddenly open and close the water-faucet, and the pulse along the rubber tube may be felt each time fresh water is admitted.

Examination of the heart.—Secure from the butcher an ox heart. Carefully examine the exterior and the number of tubes. Dissect and examine the cavities. Search for the valves. Notice the thickness of the walls.

To examine red corpuscles.—Puncture the skin of the thumb with a needle and let out a small drop of blood. Spread the blood on a slip of glass, and examine under a compound microscope. The blood must be only a very thin smear on the glass, or the separate corpuscles will not be seen.

CHAPTER XI

RESPIRATION

The ocean of air.—The air is a great ocean of gas which forms the outer layer of the earth. Air moves with the earth, and is a part of it. Nothing is outside the earth unless it is beyond this layer of air. Man, properly speaking, lives beneath the surface of the earth. His natural place is in the plane where the ocean of air rests upon the oceans of water and the land.

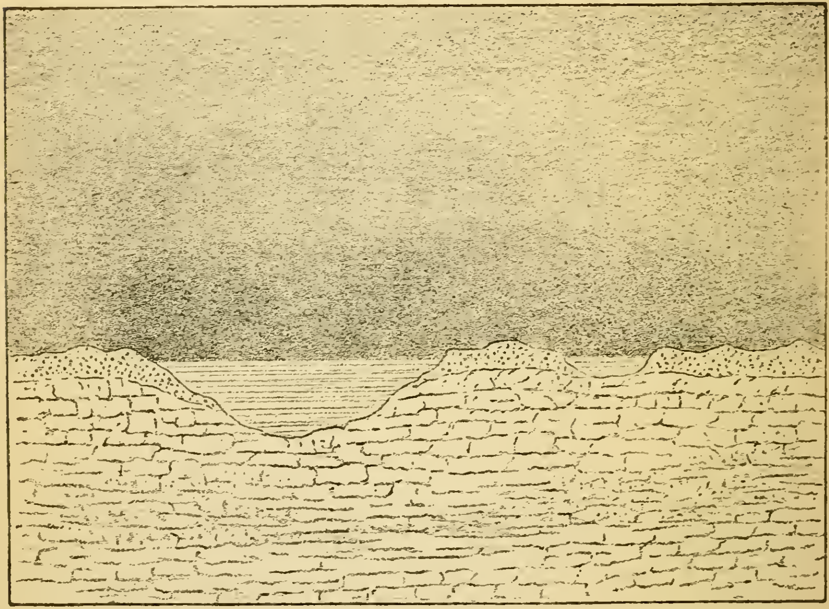

Fig. 74.—The three envelopes of the earth. Man's abode is at the bottom of the outer layer.

The depth of the aerial ocean is not known, for it has no definite surface at the top, but shades off into lighter and lighter air until none exists. It is very probable that some air exists as high as 1000 miles above the lands and water.

Since air has weight, the layer next to the land is pressed upon with considerable force. At sea level the pressure is about 14.7 pounds on every square inch of surface. Since air, like all gases, is very compressible, it is quite dense at the bottom. Each cubic foot of air at sea level will weigh 1.28 ounces.

Man and other land animals are fitted to live in this lower dense layer of air.

The air is composed of several gases which are mixed together by diffusion.

The most important one is oxygen. Oxygen is the breath of life, and man is dependent upon it for every minute of his existence.

The relation of man to this medium in which he must live, forms the topic of discussion in this chapter.

What respiration is.—Respiration is a process by which an exchange of gases takes place between the air and the tissues of the body. The oxygen, taken from the air in the lungs, is carried by the red corpuscles to the cells of the body. The blood takes up in exchange the carbon dioxide and other tissue waste, and conveys them back to the lungs, where they are given out to the air.

This broad definition would necessitate our tracing the air from the nostrils to the cells of the body and back again.

The part of the process from the lungs to the cells is called *internal respiration*, and is treated here under the subject of the circulation of the blood.

The first part of the process—from the nostrils to the lungs and return—is called *external respiration*, and is the proper subject of this chapter.

Why respiration is necessary.—Many very small animals have no lungs and no blood, and yet their life, like that of man, depends on their taking food and having it combine with oxygen of the air. They are so small, however, that they do not need special organs. They absorb their food and air through the surface of their bodies.

In man and all higher animals the body is large, and most of the cells lie far beneath the surface. For this reason man needs special apparatus to carry both the food and the oxygen to the cells.

What oxygen does for the cells.—Roughly speaking, it may be said that oxygen does for the body what a draft of air does for the steam-engine.

In the boiler of the engine the oxygen combines with the burning coal, producing heat and energy, while carbon dioxide and water pass up the chimney as waste products of combustion.

In the body the oxygen combines with the food in the cell, producing heat and energy, while carbon dioxide and water pass out at the lungs as waste products of combustion.

The cell appears to have the ability to store up both food and oxygen to a limited extent, and then have them unite in combustion when energy and heat are needed. Practically all such combustion takes place *in the cells* and under the control of the nervous system.

Organs concerned in external respiration.—The respiratory tract, through which air is brought into close contact with the blood in the lungs, consists of the *nostrils*, *pharynx*, *larynx*, *trachea*, *bronchi*, *bronchial tubes*, *infundibula*, and *air-sacs*. The passage of air in and out through this tract is brought about chiefly by movement of the *ribs* and *diaphragm*.

The nostrils.—The nostrils are lined with a mucous membrane, which is always kept moist with a secretion of mucus.

Particles of dust and minute germs are lodged on the sticky mucus, and thus the air is strained on its entrance to the respiratory tract. The mucous lining is underlaid with a net-work of blood-vessels, and by this means the air is also warmed in the nostrils.

Larynx.—From the nostrils the air passes into the pharynx, which has already been described as a box with seven openings.

One of these openings is the voice-box, at the top of the windpipe. It is called the *larynx*.

Across the top of the larynx are stretched the membranes called the *vocal cords*. The opening between the vocal cords is the glottis. The epiglottis stands ready to close the glottis whenever anything is swallowed, but at all other times the glottis is open. The larynx is constructed of cartilage. "Adam's apple" is a projection of one of the cartilages of the larynx.

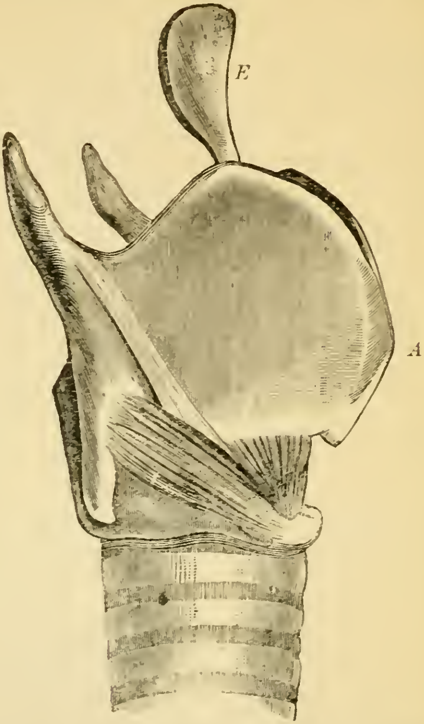

FIG. 75.—The larynx. *E*, epiglottis; *A*, "Adam's apple."

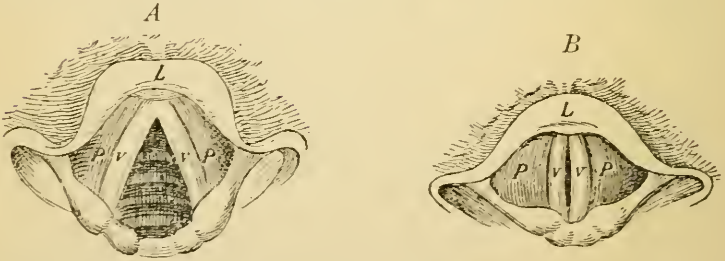

FIG. 76.—Vocal cords. *V V*, true vocal cords; *P P*, false vocal cords; *L*, epiglottis. *A*, cords open, as in breathing; *B*, cords drawn close together, as in speaking and singing.

The trachea.—The trachea, or windpipe, is a tube about one inch in diameter and extending from the larynx downward for a distance of about four and one-half inches, where it divides into two branches called the *bronchi*.

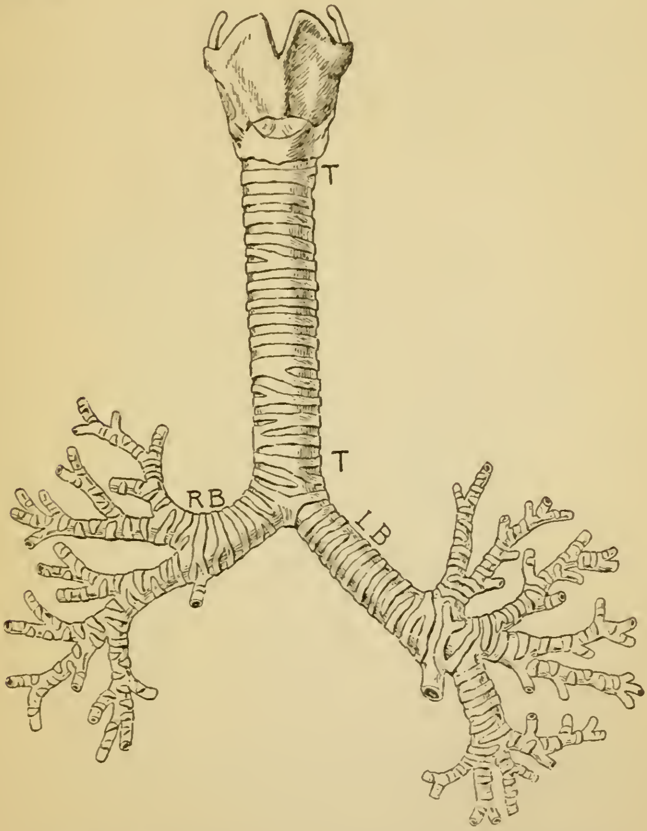

FIG. 77.—Trachea and bronchi showing the rings of cartilage. *T* to *T*, trachea; *LB*, left bronchus; *RB*, right bronchus.

The trachea is kept open by some sixteen to twenty incomplete rings of cartilage of about the shape of a horse-shoe. The incomplete part of the rings is on the posterior side, where the tube is completed by a connective tissue. Against this part lies the œsophagus. While food is being swallowed, the windpipe is more or less closed by the pressure upon its soft side.

The whole tube is lined with mucous membrane whose surface-cells are ciliated epithelium. (See page 25.) The cilia are an interesting example of provisions within the body for the care and protection of important organs. Cilia line nearly the whole respiratory tract, beginning in the nostrils. None are found in the air-sacs. They are not hairs, but minute projections of the cell material which wave constantly back and forth. Their movement is more rapid in a direction towards the outlet of the air-passages, and thus any objectionable substance in the lungs or windpipe is slowly pushed up to the throat, where it may be coughed up.

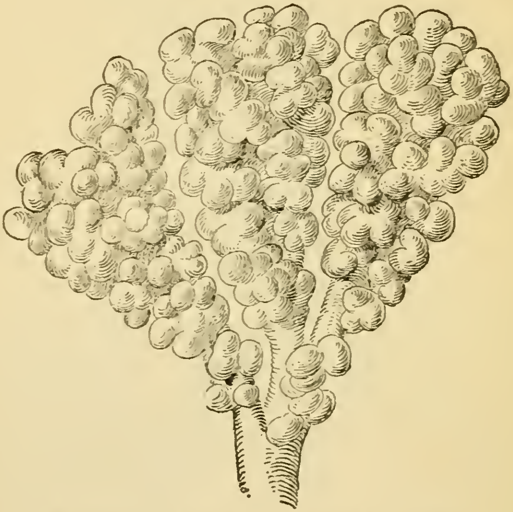

FIG. 78.—Infundibula and air-sacs.

The bronchi have a structure similar to that of the windpipe, and in fact are only a continuation of the windpipe in two branches.

The right bronchus is about one inch long, and the left one twice as long, but of smaller diameter.

Bronchial tubes.—After the bronchi enter the lungs they are called *bronchial tubes.* These tubes divide into smaller and smaller branches, and are distributed to every part of the lung tissue. They finally end in conical expansions called *infundibula*, which are covered with clusters of air-sacs having somewhat the appearance shown in Fig. 78.

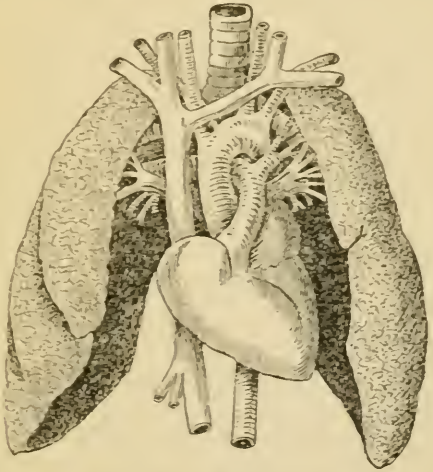

FIG. 79.—The lungs.

The lungs.—The lungs are the most important organ of respiration. They are two in number, the right and left, and they occupy most of the space within the walls of the thorax. The weight of the two lungs together is about forty to fifty ounces, the right one being somewhat heavier and larger than the left one.

Lung tissue is composed of the numerous bronchial tubes with their terminal air-sacs; a net-work of arteries, capillaries, veins, and lymphatics; and an abundance of elastic tissue binding all together. It is the least dense of all the tissues of the body, being only about one-half as heavy as the same volume of water.

The walls of the air-sacs are very thin, and blood capillaries lie just outside. The sacs are very small, but exceedingly numerous. The total number has been estimated at between five and six millions, and their total area as twenty square feet. When they are filled with air the exchange of gases readily occurs.

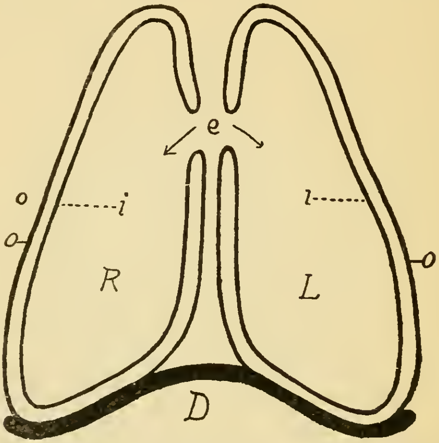

FIG. 80.—Diagram showing pleura. *R*, right lung; *L*, left lung; *e*, entrance of bronchi and blood-vessels; *i*, part of pleura which adheres closely to surface of the lung; *o*, part of pleura which adheres to chest wall. The space between *i* and *o* is called the pleural cavity, though the two are in contact; *D*, diaphragm.

The pleura.—Each lung is enclosed in a serous membrane called the *pleura*. The pleura adheres tightly to the lung, and completely covers it except at the point where the bronchi and blood tubes enter it. At this point the pleura turns back, as shown in the diagram, and lines the walls of the thorax. Thus each pleura is a closed sac, and there is no communication from the one to the other.

The space between the pleura on the lungs and that on the walls of the thorax is called the *pleural cavity*. In fact, however, there is no space between, but the two linings press against each other. Since they are very smooth and are kept moist by secretions, they glide upon each other without friction when the lungs move as in breathing.

Inhalation.—It is a principle of physics that a body, free to move, will always move in the direction of the greater force. Air is no exception to this law. If we can produce a condition in the lungs such that the pressure of the air *out* through the windpipe is less than the pressure *inward*, air will be forced into the lungs. This condition is brought about chiefly by movements of the ribs and diaphragm.

Action of the ribs.—The ribs form a true joint with the dorsal vertebræ and pass around the chest to the front, where they (all but the two pairs of floating ones) are joined by their cartilaginous ends to the sternum. Ribs do not pass straight around the chest, but droop considerably in front. The contraction of muscles will raise the sternum and elevate the front end of the ribs. This will increase the capacity of the chest, and air will rush into the elastic lungs and expand them till they fill the chest as before.

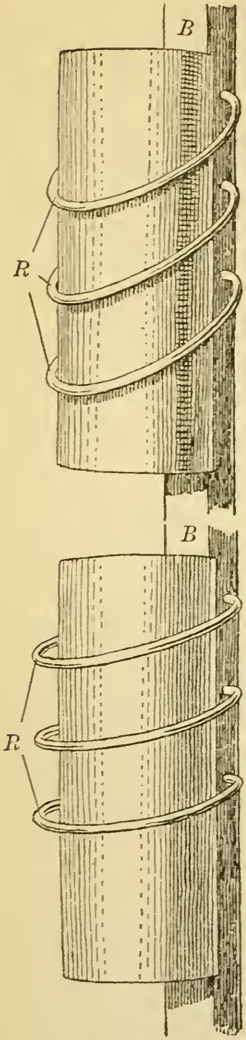

FIG. 81.—Illustrating the enlargement of the chest by elevation of the ribs.

The ribs also droop at each side of the chest, and between them are *intercostal* muscles, which by contraction elevate the ribs, and in this way also the chest is enlarged. (See experiment at end of the chapter.) This may be illustrated by the device shown in Fig. 81. The board, *B*, represents the backbone; the rings, *R*, the ribs; and the cylinder, the lungs.

In the first position the rings just permit the cylinder to pass through them. In the second position, where the rings are elevated, there is room for a larger cylinder or for this one to expand, as the lungs would do.

Action of the diaphragm.—The diaphragm has already been described as the dome-shaped partition between the thorax and the abdomen. The top of the dome is formed of tough connective tissue, from which layers of muscle radiate to the sides of the thorax. When these muscles contract, the diaphragm is flattened. Thus the contents of the abdomen are pushed down and the chest is enlarged. In the diagram, Fig. 82, if A and B represent the chest and abdomen respectively, it is plain that, if the diaphragm between them be flattened, the cavity A will be enlarged and B will be decreased.

The air is *not drawn in*. The enlargement of the chest produces a partial vacuum there, and air is *pushed* in by atmospheric pressure. As soon as the density of the air within is equal to that without, the flow of air will cease.

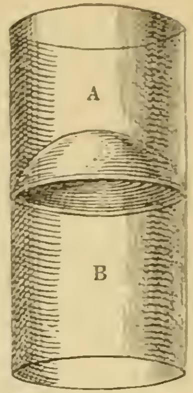

FIG. 82. — Diagram illustrating action of the diaphragm.

Exhalation.—Any increase of pressure within the lungs will tend to cause an outward flow of air called *exhalation*. Ordinary exhalation is accomplished without any muscular effort. The elastic tissue of the lungs alone tends to expel the air, and when the ribs, diaphragm, and abdominal organs settle back to their natural position, the capacity of the chest is diminished.

For forced exhalations, as in loud speaking and singing, coughing, and sneezing, other muscles are called into play. Strong abdominal muscles force the liver and stomach up against the diaphragm, thus decreasing the chest and driving the air out of the lungs. Also a set of *intercostal muscles* upon contraction *lower* the ribs, as explained in the experiment at the end of this chapter, and in that way also the chest is made smaller.

Capacity of lungs.—Lungs of average size will hold about 330 cubic inches of air. In ordinary quiet breathing only about 30 cubic inches are inhaled at each inspiration. Thus only about one-tenth of the available air-space of the lungs is ordinarily used. By an effort one may breathe in 130 cubic inches of air, and then breathe out 230 cubic inches. About 100 cubic inches of air always remains in the lungs.

Quantity of air breathed.—The quantity of air breathed varies greatly at different periods of life, and in various states of the body as to health and exercise. The adult will, on an average, breathe about eighteen times every minute. Thus he would inhale 32,400 cubic inches of air every hour.

When at vigorous work or exercise he will inhale more than twice that amount, for his food must be rapidly oxidized to produce the necessary amount of energy. The weight of the air which a man breathes is seven or eight times that of the food eaten.

Composition of air.—Water is composed of hydrogen and oxygen in the proportion of two to one parts by volume.

This is always so, because water is a chemical compound.

Air, however, is only a *mixture* of several gases, each gas being free.

The composition, therefore, may vary, but the quantity of the essential gases is quite constant.

Outdoor air contains nitrogen, oxygen, water vapor, argon, carbon dioxide, ozone, traces of other gases, particles of dust, and living germs.

Air proper is composed of five gases in about the proportion named below.

	PER CENT.
Oxygen	20.96
Nitrogen	78.00
Argon	1.00
Carbon dioxide	.03
Ozone	.01

Oxygen and ozone.—Oxygen is the part of the air upon which we are most dependent. It is exceedingly active in entering into chemical combinations with other substances. Its activity may be shown in the manner

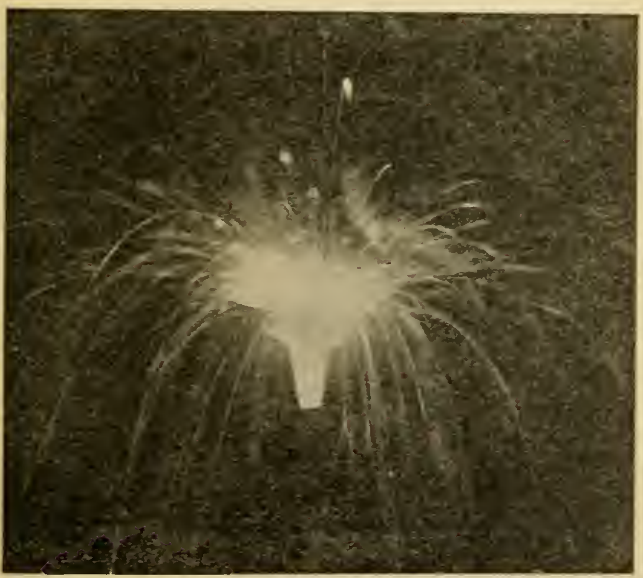

FIG. 83.—Photograph of the combustion of an iron wire in a spoon. The spoon can be dimly seen. Below it is the flame of a Bunsen burner. The white lines show the paths of particles of burning iron.

represented in Fig. 83 (see experiment at end of chapter), where it is rapidly forming a chemical combination with the material in an iron wire.

Ozone is a concentrated kind of oxygen, and, though it forms but a small per cent. of the air, it plays an important part in keeping the air pure.

Nitrogen and argon.—Nitrogen and argon are very inert gases. Until recently they were considered as one gas. Both are important substances and are necessary to life, but they are only passive agents in respiration. Oxygen cannot be breathed in a pure state, but must be diluted with about four times its weight of nitrogen and argon.

Carbon dioxide.—Carbon dioxide exists in the air in only small quantities, and yet it is essential to the life of plants and, indirectly, to the life of all animals. It is one of the essential foods of the vegetable world.

Every green leaf, while the sun is shining upon it, is busy making starch by a chemical union of water and carbon dioxide. The leaf gets the water from the sap, and the carbon dioxide from the air. For every molecule of starch thus made, twelve atoms of oxygen are set free into the air.

The chief sources of carbon dioxide are the breathing of animals and the burning of fuel.

An adult at work will breathe out one cubic foot of carbon dioxide every hour.

The burning of a ton of coal will give off about 67,200 cubic feet of carbon dioxide.

For every 100 cubic feet of fuel gas consumed, 200 cubic feet of carbon dioxide are given to the air.

This gas is constantly being used up by the growing vegetation, and a large quantity of oxygen is set free.

Thus vegetables and animals are dependent on each other.

Changes in inspired air.—The blood which is sent by the right ventricle of the heart to the lungs is purple because the oxygen has been given up to the tissues. It is also loaded with carbon dioxide in solution in the blood-plasma.

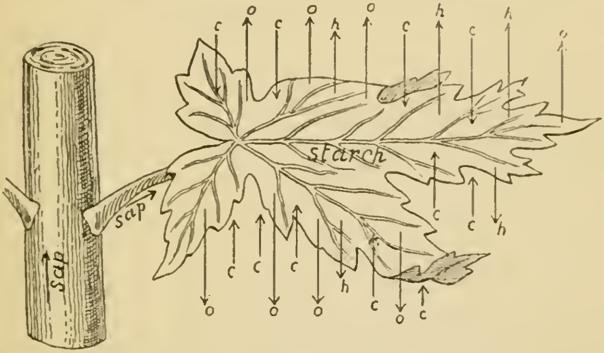

FIG. 84.—Showing changes in a green leaf. *c*, carbon dioxide; *o*, oxygen; *h*, water when in excess.

The two chief objects, then, in bringing the blood and air close together in the lungs is that the blood *may get oxygen* from the air and *give out carbon dioxide to the air.*

This exchange is made by osmosis through the thin walls of the air-sacs and capillaries.

The rapidity with which gases will diffuse may be shown by holding a jar containing hydrogen over a porous cup containing air.

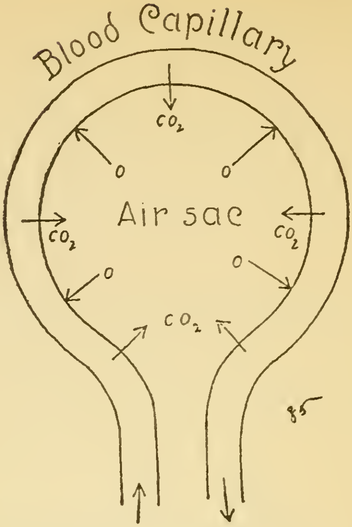
Blood Capillary
Air sac
CO_2
CO_2
CO_2
CO_2
O
O
O
O
85

FIG. 85.—Diagram illustrating the exchange of oxygen and carbon dioxide between the blood and air in lungs. *O*, oxygen ; CO_2, carbon dioxide.

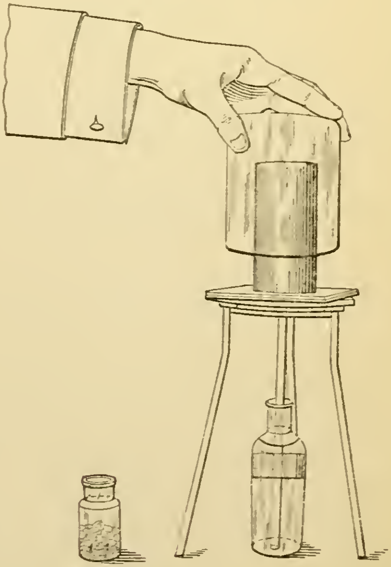

FIG. 86.—Diffusion through porous cup. (See description of experiment at end of chapter.)

The hydrogen will pass through the walls of the cup much faster than the air passes in the opposite direction, as will be shown by the escape of bubbles from the lower end of the tube. (See experiments at the end of this chapter.)

The expired air is composed of about 15 per cent. of oxygen, about 4 per cent. of carbon dioxide, 78 per cent. of nitrogen, and 1 per cent. of argon. Thus a large quantity of oxygen is taken from the air and carbon dioxide added to it, but other gases of the inspired air are not sensibly changed.

Hygiene of respiration.—Breathing and eating are the two most important things we do, as far as concerns health and vigor of both body and mind.

Just as neither coal nor oxygen would be of any use as a source of energy unless they could combine with each other, so also our food and the oxygen must unite in slow combustion within the body.

Just as it requires good fuel and a good draft of air to maintain a hot fire, so it takes good food and good air to furnish the heat and energy needed in a vigorous body.

How air becomes impure.—Pure air and proper breathing are quite as essential as good food. Air in the open country is pure because any impurities there will be mingled by winds and air-currents with a great mass of air.

Air in the streets of a crowded city is not so pure as in the country.

The most impure air is usually found in rooms, shops, railway-carriages, and other enclosures where people live.

The air in a close room may soon become unfit to breathe. Every respiration takes oxygen from it and adds carbon dioxide to it. A burning lamp is doing the same. An oil-stove, however "odorless," is vitiating the air in the same way.

In addition to the carbon dioxide, certain poisonous organic substances are exhaled with each breath.

When such air is breathed over again, the amount of carbon dioxide excreted by the lungs grows less and less. This shows that the activity of the cells has diminished because the proper supply of oxygen is not furnished.

Such a condition soon results in weakness, and makes the body an easy prey to disease.

Ventilation.—Ventilation is a process by which the air in an enclosure is removed and fresh air brought in to take its place.

When the air contains over .06 per cent. of carbon dioxide (from breath) it is unfit for breathing. The carbon dioxide alone is not so objectionable, for one may safely breathe air containing a much larger per cent. of it. But along with carbon dioxide from the lungs always comes a quantity of organic poisons, which are the chief cause of impurity in the air of living-rooms and in halls where people meet.

It is easy to determine approximately the quantity of carbon dioxide in the air, and this can be taken as an indication of the quantity of other impurities if all came from the lungs.

A lamp may give off more carbon dioxide to the air than a man does in the same time, and yet not vitiate the air as much.

The purpose of ventilation is to supply air in such a condition that every inhalation will supply the proper quantity of pure oxygen to the blood, and every exhalation will remove a proportionate amount of waste.

Fresh air must be admitted into the room where people stay for any length of time; otherwise the fire of life is sure to burn low. Man does not have appetite for fresh air as he has for food, but notice of bad air is given by drowsiness, headache, inability to study, and pallor of the skin.

The sense of smell will also serve as a guide to one coming in from the fresh air.

To keep the air fit for respiration, 3000 cubic feet of fresh air should be supplied to each person every hour.

Methods of ventilation.—Ventilation is ordinarily an easy matter in summer time, when doors and windows may stand open. But in cold weather, when the air in the room must be kept warm, there is great danger that the same air may be breathed over and over.

Many private houses and public buildings are ventilated with a constant stream of fresh warm air, which is brought in from pure sources on the outside and passed over a furnace or hot coils before it enters the room.

This plan may be more expensive than some other methods, but if it is properly constructed and operated, it will save doctor bills, and will increase the earning capacity of those who are thus supplied.

Steam and hot-water radiators placed in a room will heat the air and cause it to move about by convection *within* the room, but will not provide ventilation.

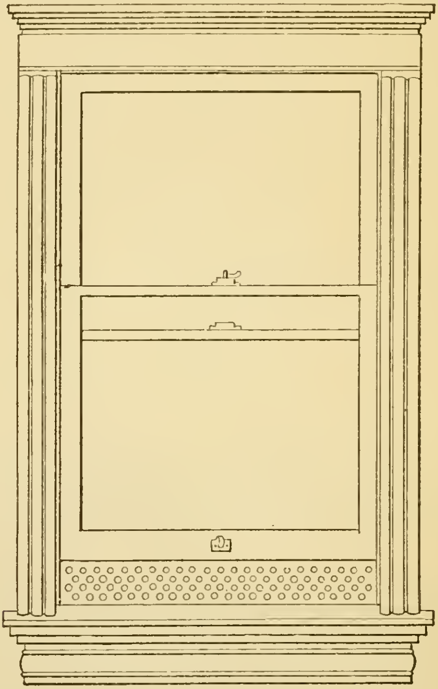

FIG. 87.—Window arranged for ventilation.

A stove or fireplace connected to a chimney that "draws" well will remove a considerable quantity of air from a room, and fresh air will come in through the cracks at doors and windows. This, however, will not be sufficient except for one or two persons.

A good plan, where special means of ventilation have not been provided, is to raise the lower sash of a window a distance of three or four inches and place beneath it a board or, better, a perforated zinc box. The zinc box should be about one inch thick, three inches wide, and just long enough to fit in beneath the sash. The perforation in the two sides should not be opposite. In this way fresh air will be admitted between the sash, and other air will go out through the holes in the zinc without causing a draft in any part of the room.

Sleeping-rooms need special care. It is better to sleep in a cold room in winter time, for then the necessary covers for the night will be needed at once on retiring, and windows may be freely opened. Sound sleep is not possible in bad air.

Good breathing.—Though one may be supplied with fresh air, he may not get the full benefit from it unless he breathes it to the blood in plentiful quantity.

Tight clothing about the waist displaces the liver, stomach, lungs, and other organs. This not only gives to the body a deformed appearance, but makes free respiration impossible.

After all proper conditions are complied with, it is still necessary for each person to *make a business of breathing* for a short time each day.

This may be done in the country or park, on the porch, or in a room before an open window.

A good exercise of this kind is one where the person stands erect, expands the chest to its fullest capacity, then, holding the breath, pushes with all the might with one hand against the wall for a few moments, stands erect again, exhales, then fills the lungs once more and pushes with the other hand.

This may be repeated till one is slightly dizzy. In a few days the exercise can be prolonged. Such breathing will not only furnish warmth and vigor for a winter day, but will greatly diminish liability to colds.

Dust in air.—The appearance of air gives but slight indication of its fitness for breathing. Air always contains a large number of particles which are not visible to the naked eye except under special conditions, as when a beam of light is admitted into a darkened room.

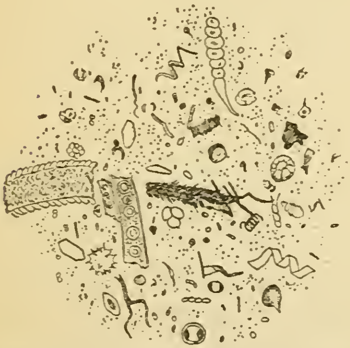

FIG. 88.—Particles of dust from a living-room, magnified.

Fig. 88 shows some dust particles as seen through a high-power microscope. These are such as are found in the air of dwelling-rooms, and consist of a variety of particles of dead matter as well as living germs.

The particles are very minute, but exceedingly numerous. A careful count has shown that in country air there are about 100,000 particles in every cubic inch, and in towns there are from 1,000,000 to 50,000,000 in a cubic inch.

It is not possible to avoid all dust particles, and so provision is made in the air-passages to prevent their accumulation in the lungs, as has already been explained.

Dusty air, however, should be avoided as far as possible, not only because the dust itself is objectionable, but also because of the germs of disease which are liable to be present in larger numbers when dust is plentiful.

Living germs in the air.—About one out of every seven deaths in civilized countries is caused by consumption of the lungs. This disease is aptly called the "great white plague." In all cases it is caused by breathing into the lungs the living germs which cause that disease. There they multiply and destroy the lung tissue.

There is no danger of contracting "consumption," or tuberculosis of the lungs, if the air is free from tubercular germs.

The careless spitting of a consumptive may result in a spread of his disease to others. The sputum may dry in the room or on the street, and then be blown about with the dust. The germs, though dry, will live for a long time in a dormant state. As soon as they fall upon a spot where they can get moisture and food, they become active and increase in number.

Old wall paper and carpets may have, clinging to them, many germs of this and other kinds. To sweep such carpets, or dust such walls, only sets afloat the dust and germs. The occupants of the room are then compelled to breathe them, or the dust is allowed to settle upon the books, chairs, tables, and clothes in the room, and will be afterwards stirred up by every movement in the room. Careful dusting with a moist cloth is good, but is not sufficient.

Ordinary house-cleaning may remove the dirt which can be seen, but such dirt is often the least objectionable from a sanitary point of view. A room which has long been in use as a living apartment cannot be *cleaned* unless, in addition to the ordinary means, it be thoroughly fumigated. This should be done at least once each year, whether germs of contagion are known to be present or not.

A formaldehyde generator used according to directions will effectively cleanse a room of disease germs, without injury to the furnishings in the room and with little expense or inconvenience.

Effect of alcohol.—Every one is liable to disease at all times. Good health depends largely upon one's ability to resist disease. Good health may be defined as that condition in which the oxygen and the food unite in proper quantity to produce the available energy needed by the body, without any interference from poisons.

As already explained under "Circulation," alcohol does interfere by extracting oxygen from the red corpuscles, and the heat given off by its oxidation is more than offset by the derangements of the organs of the body.

The effect of alcohol is not always apparent, but it always interferes, to some extent, with the normal processes within the body.

A weakened condition of any part of the body makes the whole body liable to disease.

A large proportion of those who go to hospitals because of diseases of the throat and lungs, are those who have been addicted to the use of alcohol.

Continued use of large quantities of alcohol cause the lungs to become congested with blood, so that less air is breathed into them. This results in inflammation and loss of vitality, with the consequent inability to resist disease.

Tobacco smoke.—The smoke of tobacco irritates and inflames the mucous membrane of the respiratory tract. Those who smoke, especially those who inhale tobacco smoke, are particularly liable to catarrhal inflammation and colds in the head.

The most injurious effect of tobacco results from the use of the cigarette. This is not because the cigarette contains more injurious substances than other tobacco, but because of the way it is used. All cigarette smokers, except the merest novice, inhale the smoke deep into the air-sacs of the lungs. It was shown on page 178 how easily a gas can transfuse from the air-sac into the blood. After a few whiffs and inhalations from a cigarette, the effect of the poison can be felt even to the tips of the fingers and toes.

The use of the cigarette has an evil effect upon men of any age.

A boy cannot select a more effective way of stunting his growth and weakening both body and mind.

QUESTIONS FOR REVIEW.

1. Describe the atmosphere.

2. In what sense does man live beneath the surface of the earth?

3. How is man dependent on the air?

4. Define respiration.

5. What two kinds of respiration? Define each.

6. Why does man need special organs of respiration?

7. Of what use is oxygen to the body?

8. Where in the body does oxygen combine with food?

9. Name all organs concerned in breathing.

10. Why should air be breathed through the nostrils?

11. Describe the larynx and the vocal cords.

12. How is the trachea constructed?

13. Why are animals choked by swallowing a large morsel of food?

14. Describe the ciliated cells in the trachea. Of what use are they?

15. What are the bronchi?

16. What are bronchial tubes? Infundibula?

17. Describe the lungs as to location, weight, density, and composition.

18. What is the pleura? Of what use is it?

19. What causes air to move into the lungs?

20. Does the air expand the chest, or does the air go in because the chest gets larger?

21. Explain the action of the ribs in inhalation.

22. How does the diaphragm cause inhalation?

23. Construct an apparatus to illustrate how the elevation of the ribs will increase the capacity of the chest.

24. What forces the air out of the lungs?

25. How is air forced out in case of coughing and loud speaking?

26. What is the capacity of the lungs?

27. How much air can one breathe out in one breath?

28. Why can one not breathe out all the air in the lungs?

29. How much air is breathed?

30. What is the composition of air?

31. What is the most important gas in the air, and how can its great activity be demonstrated?

32. What is meant by saying that air is a mixture?

33. What is the use of nitrogen and argon?

34. Of what use is carbon dioxide in the air? What are its chief sources?

35. How are vegetables and animals dependent on each other?

36. What are the two chief objects in breathing?

37. Explain the osmosis of gases.

38. What is the composition of expired air?

39. Compare food and breathing of man to coal and draft of an engine.

40. Where is impure air found? What causes it to be impure?

41. Why does breath make it impure?

42. What is ventilation?

43. What is the purpose of ventilation?

44. How can impure air be detected?

45. Describe various methods of ventilation.

46. Why is a steam-radiator in a room not a good ventilator?

47. Describe a method of window ventilation.

48. Describe a breathing exercise.

49. How much dust is in the air?

50. What becomes of the dust we breathe?

51. How is lung consumption contracted?

52. When is a room *clean?*

53. How does alcohol interfere with respiration?

54. Why do drinkers more easily contract disease?

55. How does smoking affect the respiratory tract?

EXPERIMENTS.

Burning an iron wire in oxygen.—Fig. 83 of the text is a photograph of the burning of an iron wire in oxygen. For this experiment procure a large granite-ware spoon, and fill it full of pulverized potassium chlorate ($KClO_3$). Hold the spoon over a Bunsen flame or large alcohol lamp till the potassium chlorate is all in a liquid form. Have ready a piece of picture-cord about twelve inches long with one end slightly frayed out. Heat this end of the wire in the flame, and dip it at once into some sulphur. While the sulphur adhering to the wire is burning, hold it close to the surface of the liquid in the spoon. Keep the spoon over the flame. The iron wire will burn with the brilliant scintillation observed in the photograph.

Osmosis of gases.—Fig. 86 shows the apparatus needed for this experiment. The porous cup is the kind ordinarily used in battery jars. The open end can be closed by means of a little plaster of Paris, through which passes a glass tube. The hydrogen can readily be prepared by pouring some dilute hydrochloric acid upon some zinc in a bottle. Place the large glass jar over the bottle and collect some hydrogen. After one or two minutes, or less, lift the jar to a position over the porous jar, and watch for bubbles in the water at the lower end of the glass tube.

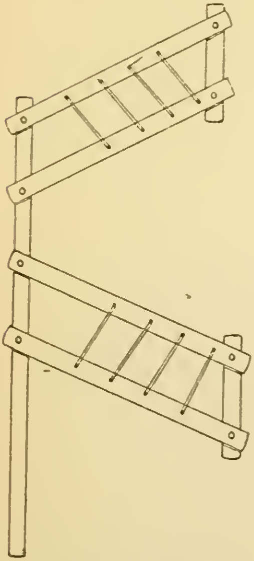

FIG. 89.—Apparatus illustrating the action of the intercostal muscles.

Action of the intercostal muscles.—Between the ribs are two sets of intercostal muscles. In one set the fibres run obliquely downward and forward. In the other, upward and forward. When the first contracts, the ribs are raised. The contraction of the second set depresses them.

This may be illustrated by the device shown in Fig. 89. Four pieces of wood are jointed together in the manner shown. Tacks are driven into the horizontal pieces at intervals of an inch or more. These two strips represent two ribs. Stretch elastic bands between the tacks, as shown in the upper part of the figure, and their elastic force will elevate the strips. This is the effect of the first set of intercostal muscles, and they are employed in inhalation. Now arrange the bands as shown in the lower part of the figure, and the strips will be lowered. This is the action of the second set of intercostals, and they are used in exhalation.

Test for carbon dioxide in the breath.—Procure a piece of unslaked lime and place it in a quart jar, nearly full of water. Shake the jar occasionally, and set aside till the lime settles and the liquid becomes perfectly clear. Decant a little of the clear liquid into a small bottle or a test-tube. Blow air from the lungs through a tube into the lime water. The water will become milky white. The carbon dioxide has united with the lime, and formed calcium carbonate, which hangs in small particles in the water.

To test the ventilation of a room.—Prepare some touch-paper by soaking any kind of soft paper in a solution of saltpetre. After the paper is dry it can be lighted, and will continue to smoke, but will not burn with a flame.

By use of the smoke from a taper made of such paper, test the doors, windows, and other points where air may enter or leave the room where you live.

Raise the lower sash just a little, and determine whether air is coming in or going out, above and below the sash. Each one should do this at his own home.

CHAPTER XII

BACTERIA

What bacteria are.—Bacteria are a class of very minute plants. During the last twenty years they have been studied very closely, and are found to be very useful agents in every-day life.

They are able to bring about changes in nature without which neither plants nor animals could long continue.

They are of use in the manufacturing industries and in the production of articles of food.

They also cause many of the diseases from which man and the other animals suffer.

A scientific study of these minute organisms is called *bacteriology.*

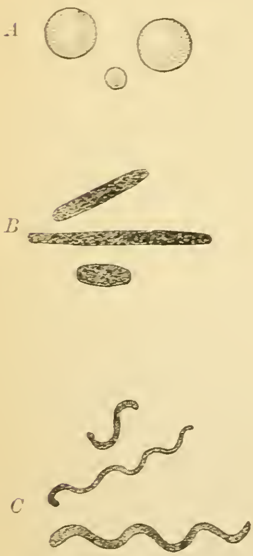

Fig. 90. — Bacteria. *A*, spheres; *B*, rods; *C*, spirals.

Shape and size of bacteria.—There are many different kinds of bacteria, but, as far as their shape and size are concerned, there are only three classes,—the *spheres,* the *rods,* and the *spirals.* The characteristic shapes are shown in Fig. 90. The spheres may vary in size, but all are very minute. If 100,000 of the largest of them were placed in a line side by side, the line would be only six inches long.

The rods are very narrow, but some kinds have considerable length.

The spirals are similar to the rods in size.

Bacteria are the smallest living things that have ever been seen in a microscope.

How they multiply.—The great number of bacteria and the rapidity with which they can multiply make them very important agents in the world for good or evil.

They increase in number by a division of one into two, two into four, four into eight, and so on.

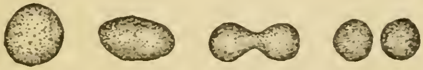

FIG. 91.—Multiplication by division.

A sphere, as seen in Fig. 91, will become elongated, and finally divide in the middle and become two.

All bacteria multiply in this way. In this respect they differ from *yeast germs*, which multiply by a method called *budding*. Yeast germs are shown in Fig. 92. This is the chief mark of distinction between yeast and bacteria.

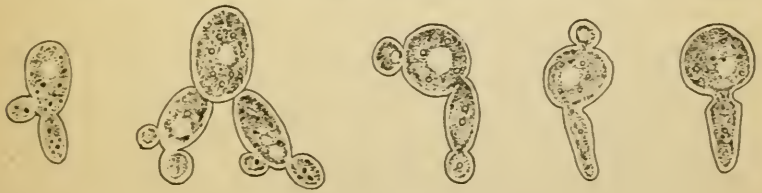

FIG. 92.—Yeast-plants.

The rapidity of multiplication of bacteria depends on many conditions, such as temperature, moisture, and the amount of food which the bacteria can get. Some can double their number every thirty minutes. At this rate it is easy to calculate that a single bacterium would in twelve hours have increased in number to more than 8,398,000.

The food of bacteria.—Bacteria are defined as plants, and yet in some respects they are like animals. Plants live on food of a very simple kind, which they can make into complex forms suitable for the food of animals. Bacteria in this respect are like animals, for they live only on complex foods, and can live and thrive only when they can get it. For this reason it is dangerous to allow certain bacteria to get a lodgement in the tissues of the body, for there they find the kind of food they want, and so will multiply and produce poisons which are the cause of many diseases.

Where bacteria are found.—Bacteria are found in every place where animals and plants live. The soil is full of them to a depth of two or three feet or more. They are in all bodies of water. All decaying matter is crowded with them. Animals, including man, contain them throughout the whole alimentary tract. They cling to the skin and the clothes. Any disturbance that will raise a dust in a room or on the street will cause great numbers of them to float in the air.

They are not found in the tissues of any healthy organ.

Use of bacteria in the industries.—Many thousands of dollars are invested in industries which are dependent on the help of bacteria. Bacteria are able to bring about many useful chemical changes. For example, when cider is allowed to stand in air it soon becomes sour and is changed to vinegar. If the cider had been boiled and then sealed from the air, it would have remained fresh.

The change to vinegar is caused by bacteria, which find in cider a desirable food. The product of their life there is the vinegar. The "mother of vinegar" is a mass of millions of bacteria.

Other kind of bacteria find milk a suitable food. One product of their life is an acid which makes the milk sour and causes it to curdle. Milk would remain sweet indefinitely if bacteria could be kept out of it.

The flavor of butter is due to the work of bacteria, and the ripening of cheese is also a result of changes which they bring about.

The "retting" of flax, by which the tough fibres of linen are separated from the woody part, is effected by bacteria.

Thus it is possible to name many arts in which bacteria play an important part. Enough has been said to show that these minute organisms are not always an enemy of man. In fact, most of them are not only harmless, but a great aid.

It is man's duty to find out their character and habits of life and turn them to good use.

Bacteria as food producers.—The *material* of our food is used over and over. Plants change simple compounds into complex ones, such as proteids, fats, and carbohydrates. Plants cannot live on these. The carbon dioxide which the animals breathe out is a suitable food for plants. Plants cannot live on the tissues of animals or plants until they are broken up into simple compounds.

This is the work of bacteria. When an animal dies in the field or a tree falls in the woods, their bodies soon soften and decay. This is the result of the work of millions of bacteria, which find there the complex foods upon which they thrive. The tissues are thus reduced to simple compounds suitable again for plant life.

If no bacteria are present, meat will not spoil and plants will not decay.

Thus the same material may go round and round, from air and soil to plants, from plants to animals, from animals through bacteria back to plants again.

The energy comes from the sunlight, and as long as the sun shines upon green leaves this circuit of food material may continue.

Yeast.—Yeast germs are classified as different from bacteria, for reasons given on page 193. But they are microscopic plants, and can produce great chemical changes in the substances in which they can live and multiply.

The chief products of their life are alcohol and carbon dioxide. The process by which this is done is called *fermentation*, and this has already been explained in Chapter IX.

The fermentation caused by the yeast-plant is the first step in the disintegration of many substances. After the work of the yeast-plant is done, certain bacteria may enter the substance and make other changes until the simple forms of plant food are produced.

Bacteria which produce disease.—Probably all bacteria are of some great use in the world. Most of them are harmless to man. A few species, however, can live and multiply in the tissues and in the alimentary tract of the body. There they produce violent poisons, which are the cause of serious sickness, which often results in death. Bacteria themselves are not so dangerous, but the violent poisons they produce are taken up by the blood and distributed through the body.

Cholera infantum.—Some germs, already described as plentiful in milk, continue to live after the milk is taken into the stomach. The effect on infants is a disease called *cholera infantum*. The effect is not so noticeable on those who are older and less delicate.

These bacteria do not enter the tissues of the body, but only continue to live in the milk after it is swallowed.

The proper precautions, particularly in warm weather, is to use only milk which has been sterilized.

Diphtheria.—The bacteria which cause diphtheria act only on the mucous membrane of the throat. There they cause a whitish membrane to form, which may close the air-passages.

Here they produce a violent poison which is absorbed into the body. The germs which produce this dread disease may easily be conveyed from one person to another. The only safety is in the complete isolation of the patient and all who live in the same house until the germs are all killed by the application of a germicide.

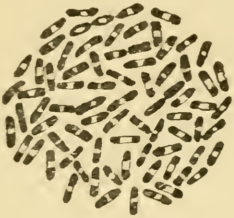

FIG. 93.—Germs of diphtheria. Klebs-Loeffler bacilli, from specimens prepared by Dr. Coplin and Dr. Bevan. Fresh culture upon blood serum. Eye-piece IV., Beck; Objective $\frac{1}{12}$ ol. im. (Leitz.) This is also the appearance when obtained directly from the throat and subjected to the same power.

Physicians are now treating the disease with success, by injecting into the blood of the patient a preparation called *diphtheria antitoxin*. It is obtained from the blood serum of horses which have been purposely caused to have the disease.

In this way not only have diphtheria patients been cured, but those who were exposed to the disease have been made immune from its attack.

Lock-jaw.—The dreaded disease called *tetanus*, or *lock-jaw*, is caused by germs which have the appearance shown in Fig. 94. These germs are plentiful in the soil, and may be introduced into the flesh through a wound in the foot or in many other ways.

The bacteria themselves are confined to the locality of the wound. There they produce a violent poison, which is taken up by the blood. More than the usual number of cases of lock-jaw occur after each Fourth of July, as a result of the admission of these bacteria into wounds caused by fire-crackers and toy pistols.

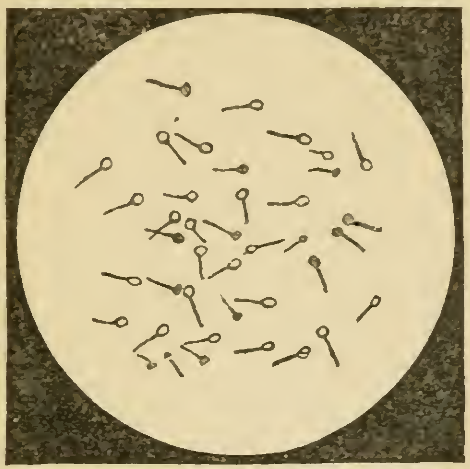

FIG. 94.—Germs of lock-jaw.

Tuberculosis.—Tuberculosis is caused by bacteria of the rod-shaped kind. This disease may be located in various places in the body, but is commonly found in the lungs. There the bacteria thrive on the lung tissue.

It was once supposed that tuberculosis could neither be prevented nor cured. Now it is known that, with proper care, both prevention and cure are possible.

It is not possible, in most localities, to avoid breathing the germs; but it is possible to have such healthy lungs and such a robust body that they cannot gain entrance to any part of the lung tissue.

The contraction of colds that "settle" in the throat or on the lungs, furnishes favorable conditions for the germs of pneumonia and consumption. If, in addition to this, the body be poisoned by the inhalation of cigarette smoke and the drinking of alcohol, the body's power of resistance is also greatly weakened.

It is plainly shown that one who has a weak constitution, or one who is already suffering from some affection of the lungs, may readily contract tuberculosis from others who have the disease.

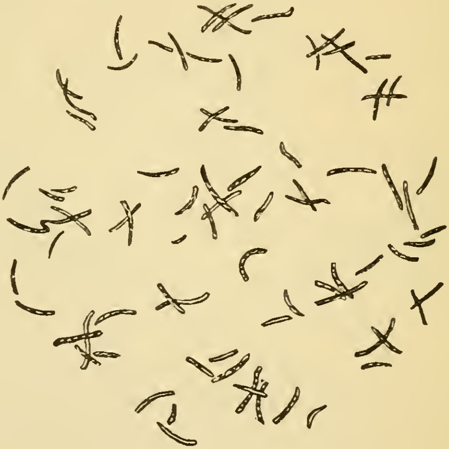

Fig. 95.—Germs of tuberculosis.

The two fundamental precautions in reference to this disease are, *a vigorous state of health*, and *avoidance of contamination from others.*

Laws of public health require that association with consumptives be avoided. This is particularly so in public places and close rooms.

Because this disease is not violent, but slow and insidious, people become careless in regard to it, though it is known to kill about 15 per cent. of the human race.

Typhoid fever.—In Fig. 96 are shown the bacteria which are the cause of *typhoid fever*. These grow in the intestines, but also often spread to the liver and other glands. They can move about by motion of the minute projections called *flagella*. Poisons which they produce are the cause of the violent fever which is characteristic of this disease.

These germs are conveyed chiefly by food and water. The water of a single well has often been the cause of an epidemic of typhoid fever. A shallow well is always to be suspected on this account.

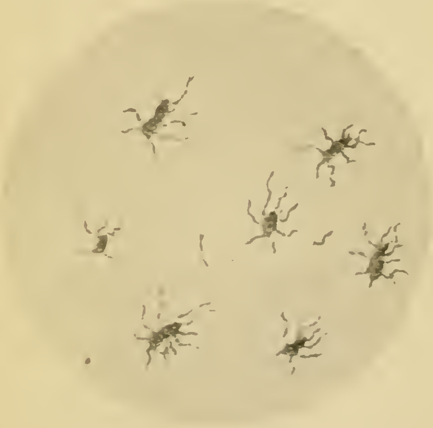

Fig. 96.—Typhoid fever germs.

Provisions in the body for resisting bacteria.—We have mentioned only a few of the diseases which are caused by bacteria. There is a constant contest for supremacy between the living cells within the body and the living cells (bacteria) without.

The cells within are an organized body, and are, as it were, fortified in their place; but the bacteria possess means of attack which are often successful if the fortifications are weak.

The body's chief means of protection are the *skin*, certain *counter-poisons* which destroy or check the growth of bacteria, and the *white corpuscles*.

The skin as a protection.—The skin may be likened to a strong wall about the organized body of cells within. Bacteria may hang in great numbers on the outside of the skin, but they cannot go through it. The linings of the respiratory and alimentary tracts act as a similar protection against most germs.

When, however, a bruise, cut, or rupture of any kind occurs in these protective coverings, the bacteria at once invade the tissues. Even a slight scratch of the skin may, for this reason, become a bothersome wound.

Surgeons now know how to dress a wound so that bacteria are kept away. The wound then heals rapidly and without the formation of pus.

Alexines.—It is not possible to prevent, at all times, the access of bacteria into the living tissue. Fortunately, however, certain substances in the blood and tissue make most bacterial life impossible there. They are called *alexines*. Although their nature is not well known, it is clear that they serve as protective agents against bacteria.

Certain disease-producing bacteria are able to neutralize the action of the alexines, and so proceed to establish themselves in the living tissue.

The white corpuscle.—After the ordinary means have failed to repel the invading bacteria, the body still has in reserve another means of defence. One of the chief duties of the *white corpuscle* is to go about through the body, apparently in search of foreign bodies, which they at once attempt to remove or render harmless. They are not confined to the blood-vessels, but can glide out into the tissues. They can take into their bodies minute particles which they dissolve or carry away even if they must sacrifice themselves in doing so. For this reason they are often called the scavengers of the body.

When bacteria gain admission to the tissue at any point, as through a wound, the white corpuscles gather there in great numbers. The wound becomes swollen and inflamed because of their presence. They appear to pour out from their bodies a secretion which checks the growth of bacteria. Many white corpuscles are killed in the conflict, and the accumulation of their dead bodies forms the substance called *pus.*

Some bacteria are able to produce such violent poisons that the white corpuscles are not able to check them. In such cases the disease will "run its course," and the bacteria would continue to multiply until death would result, except that the body itself then produces substances which are an antidote to the bacterial poisons. If the body is able to survive, the disease will reach a climax and recovery will begin. This changed condition often renders the body immune from an attack of the same disease for a certain length of time. Sometimes for a lifetime.

Argument for a robust body.—Many things in regard to bacterial diseases are not definitely known. It is well known, however, that most diseases are caused by these minute organisms, and that one whose body is robust and whose habits of life are good can most effectively resist their attack.

Drugs are effective in killing bacteria outside the body, but no drug now known will destroy them after they are lodged in the living tissue, without destroying the body as well.

The effective means of combating them comes in a natural way from within the body itself. The state of the body determines its ability to resist disease. This is a good reason for the maintenance of a body in which every cell is assimilating its due proportion of food and oxygen, and performing its part in relation to the welfare of the body as a whole.

Modern discoveries show that the physician may assist the body in its effort to neutralize the bacterial poisons. This he does not attempt to do by the use of drugs intended to kill the germs, but by injection of certain substances which will make the poisons harmless. For example, one who is bitten by a mad dog is almost sure to suffer from *hydrophobia*. The disease does not develop for some time, so that the body may be prepared for it before it sets in. The physician is prepared with material taken from the spinal cord of a rabbit which has died from the disease. This is injected into the body of the patient, first in a mild form and then in stronger and stronger doses. When the disease does develop, the body is used to the poisons produced, and no serious results follow.

QUESTIONS FOR REVIEW.

1. What are bacteria, and what do they do?
2. Describe the shape and size of bacteria.
3. How do bacteria multiply?
4. How do they differ from the yeast germ?
5. On what kind of food do bacteria subsist?
6. Why do some kinds of bacteria invade the tissues of the body?
7. Where can bacteria be found?
8. Explain the formation of vinegar.
9. Name several arts and industries in which bacteria have a part.
10. In what condition must the food of plants be? The food of animals?
11. How do bacteria prepare plant food?
12. What causes meats and fruits to spoil?
13. What is the source of the energy in food?
14. What is the cause and effect of *fermentation?*
15. How do bacteria produce disease?
16. What is the cause of *cholera infantum?*
17. What is diphtheria, and how may it be treated?
18. What is tetanus?
19. How are tubercular germs conveyed from one person to another?
20. How can consumption be avoided?
21. What is typhoid fever? How is it carried about from one to another?
22. What three provisions are made in the body for resisting bacteria?
23. How does the skin resist bacteria?
24. What are alexines, and what is their use?
25. How do white corpuscles resist bacteria?
26. Give a good reason for maintaining a robust body.

CHAPTER XIII

THE SKIN

General character of the skin.—The skin is a tough, pliable, and elastic covering over the entire outside surface of the body. The mucous membrane, which lines all cavities of the body that communicate with the outside, may be considered a continuation of the outer skin, though much modified in character. The hairs and nails are only modified forms of the skin. The claws, hoofs, and horns of animals are modified forms of the skin which covers their bodies.

Use of skin.—The chief function of the skin is to serve as a protective covering. We have already described its use as a protection against the invasion of bacteria. In every-day life the body must constantly come in contact with outside objects, and a strong covering like the skin is needed to protect the delicate parts beneath.

To make the skin a more effective guardian of the body, it is filled with terminals of nerves. Thus the mind is instantly notified when any part of the body comes in contact with outside objects.

In addition to its use as a protection, it also serves as an excretory organ. A great deal of water and some waste are taken from the blood by the glands in the skin.

The evaporation of the water from the surface of the skin has an important use in regulating the temperature of the body.

The two layers of the skin.—The skin is composed of two layers. The outer one is called the *epidermis*, *cuticle*, or *scarf-skin*. Just below it is the *true skin*, also called the *dermis*, or *cutis*.

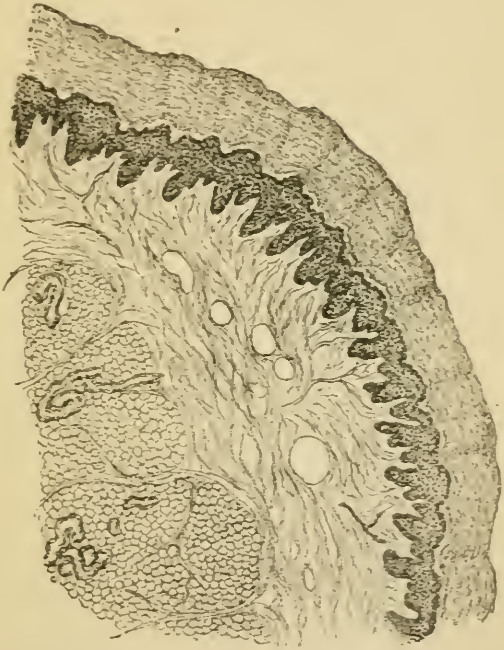

FIG. 97.—Cross-section of skin from the finger of a monkey. Photographed through a microscope.

Fig. 97 is a microphotograph of a cross-section of the skin from a monkey's finger. The two layers can be plainly seen.

The epidermis.—The epidermis is very thin on most of the surface of the body. It is thicker on the palms of the hands and the soles of the feet. It may become thick at any point where there is continuous friction or rubbing. In this way "corns" are formed on the feet by ill-fitting shoes.

The palms of a workman's hands become hard from constant pressure on the handles of tools.

Epidermis is formed of several layers of pavement epithelium. (See page 24.) The cells composing it are continually supplied from beneath, and the old ones are as constantly being worn away or drop off.

When a blister is formed, as from a burn, the epidermis is separated from the dermis.

No blood-vessels or nerves are supplied to the epidermis. The cells of its deepest layer are alive, and are nourished by the lymph which they absorb. These produce the cells of the outer layers, which gradually dry up and become cemented together, forming the horny, transparent layer which covers the whole surface of the body and protects the delicate tissue beneath.

Color of the skin.—The deeper layers of the epidermis are supplied with granules of coloring matter. The amount and kind of granules differ greatly in different persons and different races. The skin of albinos is entirely devoid of coloring matter. Negroes are abundantly supplied with it. A brunette has more of it than a blonde.

Sunlight makes the granules darker. An uneven distribution of the granules is the cause of *freckles*.

The dermis or true skin.—As shown in Fig. 98, the surface of the true skin is composed of numerous ridges. These are conical projections over which the epidermis is closely moulded. They are called *papillæ*. Some of them are filled with blood-vessels. Others are terminations of nerves of touch. The dermis is plentifully supplied with blood and nerves.

The nerve papillæ are numerous all over the surface of the body, but are especially numerous in those places where they can be of greatest service to the body, as on the tongue, lips, and tips of the fingers. On the palms of the hands they are arranged in rows, thus causing ridges which may be plainly seen with the naked eye.

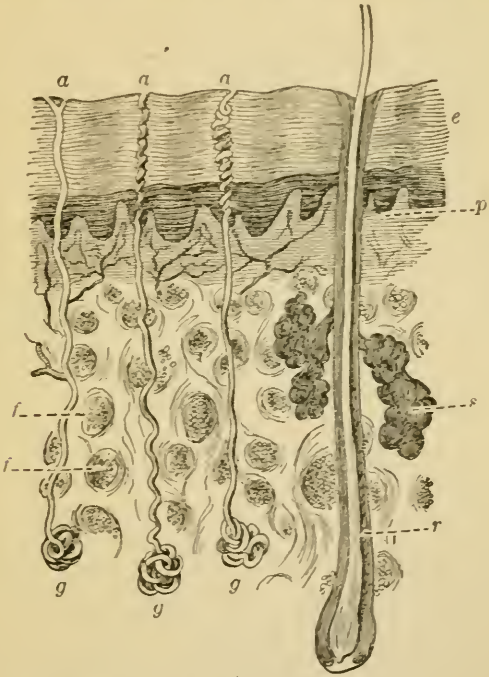

FIG. 98.—A magnified cross-section of the skin. *e*, epidermis; *p*, papillæ; *s*, sebaceous gland; *r*, root of hair; *f*, fat; *g*, sweat-glands; *a*, pores.

As may be seen in Fig. 98, the larger part of the dermis is composed of interlacing bands of connective and elastic tissue. These make the skin tough and at the same time permit it to be stretched. Beneath the skin is the loose areolar tissue in which fat is deposited, giving the skin an even surface. When the fat is used up by the body, the skin becomes wrinkled because it is then too large for the part which it covers. In the regions just below the dermis are numerous sweat-glands which communicate with the surface through their spiral ducts.

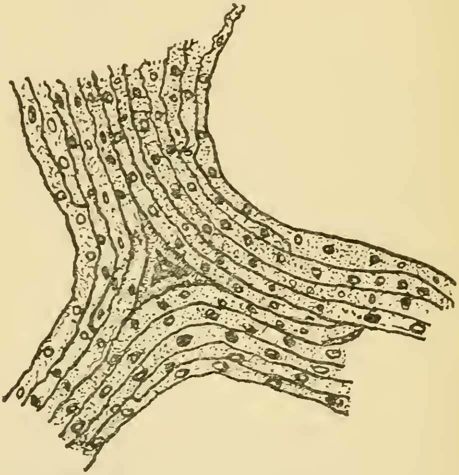

Fig. 99.—From the surface of the palm of the hand. The ridges are rows of papillæ. The dots are pores.

The roots of hairs reach down to different depths, most of them being in the fatty layer. At the sides of the hairs are oil-glands.

Sweat-glands.—With an ordinary magnifying-glass, a great number of minute spots can be seen on the ridges of epidermis on the palms of the hands. These are the *pores* of the sweat-glands. They are found in all parts of the surface of the body, but are most numerous on the palms and soles. It has been estimated that there are in all about 2,500,000 sweat-glands.

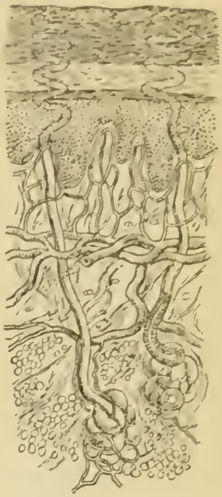

FIG. 100.—Sweat-glands.

The gland is a long tube, closed at one end and coiled up as shown in Fig. 100. Round about this coil are numerous blood capillaries, from which the gland secretes a great deal of water and some waste matter, and pours them out on the surface of the body.

Perspiration.—The escape of the excretions of the sweat-glands at the surface of the skin is called *perspiration.* It may take place rapidly, making the skin wet with sweat. It is then called *sensible perspiration* because it can be perceived by the senses.

At all other times the water evaporates as fast as it reaches the surface, and it is then called *insensible perspiration.*

The average amount of water perspired in a day is about one quart.

Insensible perspiration may be readily shown by inserting a finger into a cold, dry bottle or test-tube. The inner surface of the glass will "fog," as a result of the condensation of the vapor from the finger.

Effect of vaporization on the temperature of the body.—The normal temperature of the human body is between 98 and 99 degrees Fahrenheit. Only at this temperature can the body be said to be in a healthy condition.

The air is ordinarily cooler than the blood, and so heat is constantly being radiated from the body. Frequently, however, this is not sufficient to keep the temperature down to normal.

In addition to radiation, *evaporation* acts as a temperature regulator. A liquid cannot evaporate unless it can get heat. When sweat evaporates it can get the needed heat most conveniently from the body. Thus the body is cooled.

The body automatically regulates its own temperature. During a hot day, or at times of vigorous exercise, a large amount of sweat is poured out on the surface of the skin. Its evaporation cools the body. A warm wind feels cool if the skin is wet, because evaporation is hastened. Fanning heats the air slightly, but it increases evaporation from the skin, and so the air seems cooler. Fanning a dry thermometer will not cause the mercury to fall.

Heavy clothes keep the body warm, because they check both the radiation and the evaporation. Alcohol rubbed on the skin will cool the body more rapidly than water will, because it will evaporate faster.

Hair.—Hairs, in more or less abundance, are distributed over nearly the whole surface of the body. There are none on the palms or soles. The root of a hair is the part beneath the surface of the skin. It is enclosed in a follicle or pocket formed by the involution of the epidermis, as shown in Fig. 101. At the bottom of the follicle, the root fits over a papilla, which is supplied with blood-vessels. Thus the cells in the root of the hair are nourished and continue to produce new cells, which push the old ones ahead of them, thus increasing the length of the hair.

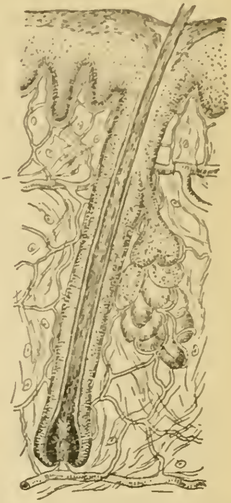

Fig. 101.—Hair-follicle.

When a hair is pulled out, a new one will grow in its place if the papilla is not injured.

The outside of a hair is covered with a single layer of flat cells which overlap like scales. The free edge of the scales lie towards the point of the hair. By rubbing a hair lengthwise between the thumb and the finger, it will be moved along root first.

The color of the hair is determined by a pigment in the cells. In old age the coloring matter is wanting, and the hair is white.

Fibres of muscle are attached to the hair-follicles. When they contract, the follicle is changed from an oblique position to one more nearly perpendicular to the surface. Thus the hair is made to "stand on end." In some animals, such as the cat, frequent use is made of these muscles.

Hair on the head is useful for adornment and for protection from heat and cold. The eyelashes and eyebrows protect the delicate organs of sight. Hairs in the nostrils and ears guard the entrance to important organs.

Nails.—Nails, like hair, are a modified form of epidermis. They consist of a *root*, *body*, and *edge*. The root is the back part where the nail is attached to the dermis, and where there is a constant addition of new cells which push the nail forward.

The body is the visible part of the nail, which is attached to a portion of the true skin called its *bed*. The nail increases in thickness by the addition of new cells from the bed.

The nail itself is quite transparent. The color observed is that of the true skin beneath. The pink color is due to the supply of blood beneath.

The *lunula*, or little moon, near the root is of whiter color because less blood flows beneath it, and it is less transparent.

Hygiene of the skin.—The skin is an exceedingly important organ as far as concerns bodily health and comfort. Its chief functions are *protection* and *excretion*. A temporary suspension of either one of these results in sickness or even death.

The skin, like any other organ, can effectively do its part only within certain limits. For example, it can, under ordinary conditions, regulate the temperature of the body, keeping it quite close to 98.5 degrees. In extremes of heat and cold, however, the unaided skin is helpless as a temperature regulator.

Clothing.—As already explained, heat is constantly leaving the body by radiation and perspiration. When exposed to cold weather, perspiration is checked by closing the pores, but radiation becomes more rapid than before. For this reason the body must be protected with proper clothing.

Clothing does not warm the body. It only prevents the escape of heat. In cold weather, then, a garment should be a poor conductor of heat. A loose woollen garment is good because much air is enclosed between its loose fibres, and air is a very poor conductor of heat.

Many workmen who are exposed to the hot sun wear woollen shirts to keep the excessive heat out.

A woollen sweater is an excellent protection during winter and at all times when there is liability of cooling off too suddenly.

The effect of the color of clothes is a matter of some importance. Black is a good absorber of heat and also a good radiator. White is poor in both.

When a black cloth is exposed to sunlight or some other source of heat, it will become warmer than the white cloth ; but when the source of heat is withdrawn the black will cool more rapidly.

A black garment will, on a cold day, allow more heat to escape from the body than a white one made of the same material.

As people ordinarily live, white is the best color the year round, as far as the absorption and radiation of heat are concerned.

Cotton and linen goods are good for summer wear under ordinary conditions. They are fairly good conductors of heat, and for that reason the body will cool by radiation if the surrounding atmosphere be cool. The greatest advantage of such goods in hot weather lies in the fact that they will readily absorb moisture from the skin and conduct it to the outside, where it can rapidly evaporate.

The kind and amount of clothing depend upon the climate, habits of life, and constitution of the body. Many of the ills of the body result from an improper kind or quantity of clothing. As a rule, a loose woollen garment next to the skin is best in winter time, and for some it is best the year round. Each one must suit his clothing to his individual needs.

Bathing.—Every pore of a healthy body is constantly perspiring. Sometimes, as on exposure to cold, the amount of matter perspired is very small. At other times, when there is danger of the body being overheated, a large amount of sweat is poured out on the surface of the body. Along with the perspired water is a considerable quantity of urea, salts, and other matter. When the water evaporates, these substances become dried on the skin and clothing.

The oil which is furnished by the sebaceous glands also causes dust and dirt to adhere more readily to the skin and hair.

In addition to this, one who is engaged in any active occupation must come in contact with more or less dirt which clings to the body.

Bathing is necessary to assist the skin in its work of excretion, and also for the mere purpose of being clean.

Beside the mere matter of removing dirt, however, a cold bath in the morning will, to some people, be a stimulus to the whole body during the day; and a warm bath just before retiring will often induce sound and restful sleep.

Times and methods of bathing.—The advice of various authorities vary in regard to the times and methods of bathing. One may bathe too often, and thus do the body more harm than good. A change of the clothing worn next to the skin is often more essential to good health than the application of water and soap. The vocation and manner of life will help to determine how frequently one should bathe. The skin may be moistened with water every day and then well rubbed with a coarse towel; but a thorough bath every week, or even every two weeks, may be sufficient under ordinary circumstances.

In hot weather or after severe exercise baths may be more frequent.

The kind of a bath is a matter to be decided by each individual in accordance with his state of health and his circumstances. Baths may be cold, warm, or hot.

The cold bath may consist in a plunge into cold water, a cold shower, the application of cold water by means of a sponge, or even dipping the hands into the water and rubbing it rapidly over the skin.

The first effect of the cold water is to close the pores and contract the blood capillaries; but this should be quickly followed by a reaction, and a warm, healthful glow should be felt all over the surface of the body. The body should be exposed to the cold water for only a very short time and then vigorously rubbed with a coarse towel. Unless a warm glow follows, the cold bath will be injurious. Persons of weak constitution should be cautious in the use of the cold bath and, if attempted at all, it should be taken in mild form at first until the body becomes used to the shock.

The warm bath is the one commonly used with soap to wash away grease and dirt. Many people will never use the hot and cold baths, but every one needs the warm bath and soap, and a frequent change of underclothing, to keep the skin in a healthy condition. Any one who can get a sponge or wash-cloth, some mild soap, and a basin of water, has no excuse for not keeping his body clean.

A clean skin and clean clothes improve not only the physical, but also the moral condition of the individual. Hot baths may be recommended by physicians in treatment of certain diseases.

Care of the hair.—A beautiful head of hair is an ornament to its possessor, but only good care will keep it so. The hair may occasionally be washed with soft water and a mild soap, but only often enough to keep it and the scalp clean. Massage of the scalp and use of the hair-brush will stimulate the roots of the hairs to healthy activity.

The natural secretions of the sebaceous glands will ordinarily keep the hair soft and glossy. If it becomes dry and loses its gloss, a little vaseline may be applied to it.

A large number of loose cells of the epidermis, along with oil which has dried on the scalp, constitutes what is called *dandruff*. It indicates a diseased condition of the scalp and is associated with a loss of hair.

Care of nails.—Clean and neatly-trimmed nails are a recommendation to any one. Dirty nails with jagged edges indicate careless habits, not only in this but in other matters. They should be cleaned every day with a nail-brush and water, and the edges should be occasionally trimmed to a smooth curve.

The epidermis which overlaps the nails at the roots and sides should be pushed back, for otherwise it adheres so firmly to the nail that the skin will be torn, forming the "hang-nail."

QUESTIONS FOR REVIEW.

1. What is the nature of the skin?
2. How does skin protect the body?
3. Why is the skin provided with nerves of touch?
4. Describe the two layers of skin.
5. How thick is the epidermis?
6. What kind of cells form the epidermis? How are they supplied?
7. Are the cells of the epidermis alive?
8. Explain the color of the skin. What causes freckles?
9. Describe the true skin.
10. What are pores? Can you see them?
11. Describe a sweat-gland.

12. What is perspiration? Describe two kinds.

13. Try an experiment to show insensible perspiration.

14. Explain fully the effect of evaporation from the surface of the body.

15. Describe the root of a hair.

16. What causes hair to grow?

17. What causes hair to stand on end?

18. Describe the nail.

19. How does a nail grow?

20. Explain the lunula.

21. What is the use of clothing?

22. Why will a woollen garment keep the body warmer than a linen one?

23. What is the effect of the color of clothing?

24. Why do cotton and linen make good summer garments?

25. Why is bathing necessary?

26. How often should one bathe?

27. What is the advantage of a cold bath? When and how should it be taken?

28. Why should clothing worn next to the skin be frequently changed?

29. What is proper care of the hair?

30. Why should nails be kept clean?

CHAPTER XIV

EXCRETION

Secretion and excretion compared.—We have seen that numerous glands are distributed throughout the body. All the glands are enclosures surrounded with cells, and opening, as a rule, by ducts out onto a free surface.

Blood constantly flows through the numerous capillaries about the cells of the gland, and from it is selected the various substances, in accordance with the purpose of the gland.

The cells of a gland may gather out liquids which are already in the blood, or they may elaborate the materials which they collect, and produce new compounds.

The hydrochloric acid in the stomach, for example, is not taken from the blood, but is made by the gastric glands.

When the material collected by a gland is for further use in the body, the process is called *secretion*. For examples, the saliva and gastric juice are secretions.

When material is collected by a gland only to be cast out of the body, the process is called *excretion*. For example, urea is excreted by the kidneys and carbon dioxide is excreted by the lungs.

Some substances are both secretions and excretions. For example, the bile is an important agent in digestion, and so may be considered a secretion of the liver; but bile would soon make the blood impure unless it be constantly eliminated; and thus it is also an excretion.

The chief excretory organs.—The chief organs concerned in excretion are the *lungs*, *skin*, *liver*, and *kidneys*.

These have all been described except the kidneys. In this chapter we briefly refer to the work of each, and describe the work of the kidneys in full.

The lungs.—The lungs are excretory organs of very great importance. We have already compared breathing to a draft of air through the burning fuel of a steam-engine. In the engine the air enters below the grate, and the waste products of combustion pass out through a chimney above.

In the body the air is supplied to the blood in the lungs and the products of combustion are returned by the same channel. Thus the air-passage serves both for damper and chimney.

The chief substance excreted by the lungs is carbon dioxide (CO_2). This is the chief product of combustion of coal, wood, coal-oil, or any kind of carbonaceous substance.

Some organic substances are also excreted with every exhalation. The character of these substances is not well understood; but there is no doubt of their presence in the breath and their vitiating effect on the air in a close room.

Water is also excreted in large quantity by the lungs,

The skin.—While the skin is chiefly an organ for the protection of the body, it also has an additional double function of secretion of waste substances and the regulation of bodily temperature. Thus the skin may be regarded as both secretory and excretory. Its chief excretions are water, urea, and salts.

There is a close relation between the skin and the kidneys. When the excretions of the skin are large, the kidneys are relieved of much of their work; when the glands of the skin are inactive, more work is thrown upon the kidneys.

The liver.—The excretions of the liver depend upon the kind of substances in the blood. As already explained, the liver is a most efficient guardian of the health of the body. Nothing gets from the stomach or intestines into the general circulation until it has first been tested by the liver, and many substances that would be injurious are either changed in their character or excreted.

Bile is an excretion of the liver. If the bile should remain in the blood, serious disorders are sure to follow. It is made to serve a useful purpose in intestinal digestion, and much of it may again enter the portal veins and be again excreted, or secreted, by the liver.

Kidneys.—The kidneys are among the most important of the excretory organs. A man could not live more than one day if the action of his kidneys would cease.

They are two in number and are located in the abdomen, one on each side of the spinal column, in the region of the loins.

Each is about four inches long, two inches broad, and one inch thick. They are shaped somewhat like a bean,

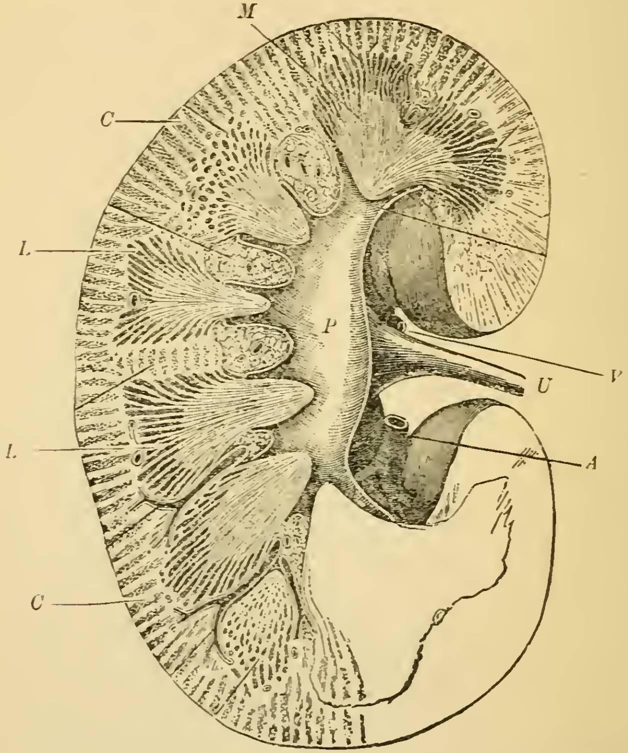

Fig. 102.—Cross-section of kidney. *C*, *C*, cortex; *M*, pyramids of Malpighi; *L. L*, medulla; *P*, pelvis; *A*, artery; *V*, vein; *U*, ureter.

and on the side towards the backbone is a depression called the *hilum*. Three tubes enter the kidney at the hilum. One is the renal artery, which carries blood to the kidney; another is the renal vein, which carries the blood away; and between them is the *ureter*, which carries the excretions of the kidney to the bladder.

Internal structure of the kidney. A longitudinal section of a kidney would have about the appearance shown in Fig. 102. The ureter on entering the kidney spreads out, forming a cavity called the *pelvis* of the kidney. Projecting into the pelvis are a number of pyramids, from eight to eighteen in number, and known as the *pyramids of Malpighi*. The pyramids project from the *medullary layer* of the kidney. Surrounding the med-

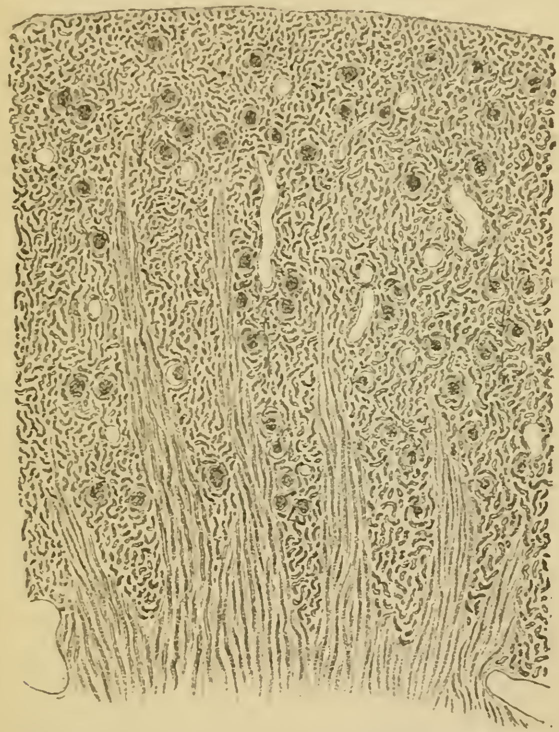

FIG. 103.—Section of cortex of a kidney, showing Malpighian bodies slightly magnified.

ullary layer is the *cortex*. The kidneys are enclosed and held in place by a capsule of fatty areolar tissue.

Microscopic examination of the kidneys.—Minute examination of the cortex shows that it contains numerous spherical bodies about $\frac{1}{120}$ of an inch in diameter. These are known as the *Malpighian bodies.* It is in these that the excretion of the kidney is chiefly done. Each little sphere is composed of two parts, as shown in Fig. 104. Within is a roll, or tuft, of capillary blood-vessels, to which blood is supplied by an artery called the afferent vessel. Leading out of the tuft is an artery called the efferent vessel. This again breaks into capillaries around the convoluted tubule, and these are gathered into *veins.* The tuft of capillaries is enclosed in a capsule from which a tube, called the *uriniferous tubule,* carries the excretions to the pelvis of the kidney.

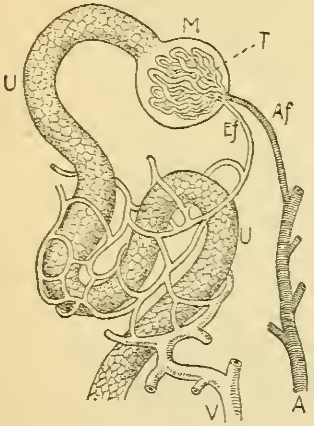

Fig. 104.—Showing structure of Malpighian body and uriniferous tubule. *A*, artery; *Af*, afferent vessel; *M*, Malpighian body; *T*, tuft of blood capillaries; *U*, uriniferous tubule; *Ef*, efferent vessel; *V*, vein. The blood first passes through the capillaries of the Malpighian body and then through the capillaries about the uriniferous tubule.

The uriniferous tubules begin at the Malpighian bodies in the cortex and pursue a circuitous route through the cortex and the medullary layer to straight collecting tubes which open at the apex of the pyramids into the pelvis of the kidney. Fig. 105 is a highly-magnified section of kidney, showing some branches of a collecting tube. All the secretions are thus brought to the pelvis and drained off by the ureter.

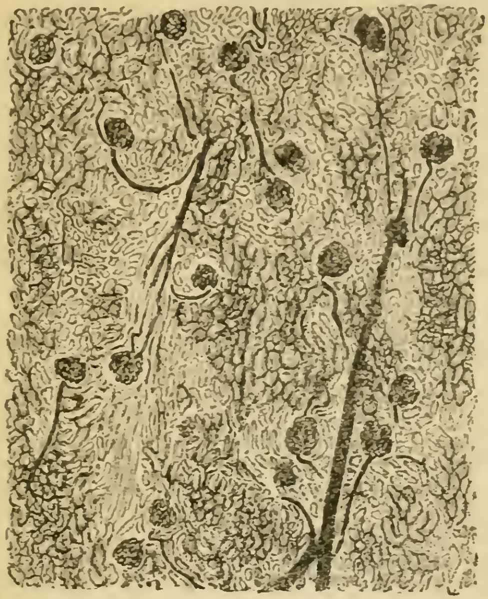

FIG. 105.—Section of cortex of kidney, highly magnified, showing Malpighian bodies and the tubes leading to the pelvis of the kidney.

The excretions of the kidney.—The substances excreted by the kidneys are urea, salts, other waste, and a large quantity of water. The amount of liquid excreted in one day is about three pints, about one ounce of which is urea.

The chief function of the kidneys is to excrete urea. The water is necessary that the other substances may be in solution and thus be carried along.

The chief excretion of the Malpighian bodies is water.

The urea is excreted by the cells which line the uriniferous tubules.

Urea is the product resulting from the use of proteid food. In the chapter on food it was shown that proteid is the only food which contains nitrogen. Urea also contains nitrogen. The chemical symbol for urea is CON_2H_4. Urea is gathered from the blood current by the *liver*, and then the kidneys, with a little help from the skin, excrete this waste product of the proteids. When the amount of nitrogen excreted is equal to the amount of nitrogen in the proteid food, there is said to be *nitrogenous equilibrium.* In this case the muscles neither gain nor lose in weight. In case of starvation the urea continues to be excreted, but it results from the fact that the muscles themselves are being used as proteid food. Thus the muscles waste away and the body loses in weight.

Diseases of the kidneys.—When the kidneys are removed from an animal, death speedily ensues. The urea accumulates in the blood and produces blood-poisoning.

Even a partial and temporary suspension of the work of the kidneys always results seriously to the welfare of the whole body.

Colds often cause an affection of the kidneys by causing the skin to suspend its work as an excretory organ. Extra work is thus thrown upon the kidneys, and, if it is overworked, a diseased condition is produced.

Alcoholic drinks injure the kidneys more, probably, than any other known cause.

The cells of the tubules and Malpighian bodies become changed, so that they no longer perform well their natural functions. Albumen of the blood is then often allowed to pass out of the capillaries with the other secretions. This condition is known as Bright's disease. Eminent physicians say that alcoholic drinks are one cause of this fatal disease.

Fatty degeneration of the kidneys is another result of using alcoholic drinks. Parts of the tissue of the kidney are replaced by fat. Thus the secreting organ is in fact decreased in size, for the fat can have no part in the work of excretion. Extra work is thus thrown upon the remaining parts of the kidneys, or the blood is allowed to pass on through without proper purification, and the whole body suffers the consequence.

Alcohol also, as already explained, interferes with digestion and the excretions of the liver. Thus injurious substances are introduced into the circuit of the blood. The kidney attempts to eliminate these in addition to its natural work. As a result the kidney is overtaxed and becomes inflamed and diseased.

Over-eating, also, or the eating of rich and highly-seasoned food, is the cause of much kidney trouble.

All parts of the body suffer from any affection of the kidneys because the purity of the blood is at once impaired.

QUESTIONS FOR REVIEW.

1. What is the source of the hydrochloric acid in the stomach?
2. What is secretion? Give examples.
3. What is excretion? Give examples.

4. Is bile a secretion or an excretion?

5. Name the chief excretory organs.

6. Describe the excretions of the lungs.

7. Do the air-passages correspond to the damper or the chimney of a stove?

8. How can you show that there is water in the breath?

9. What does the skin excrete?

10. Is the water in sweat an excretion or a secretion?

11. For what two purposes is bile produced by the liver?

12. Locate and describe the kidneys.

13. Make a drawing of a section of a kidney, showing cortex, medullary layer, pyramids, pelvis, ureter, and blood-vessels.

14. Describe a Malpighian body.

15. Describe a uriniferous tubule.

16. What is excreted by the kidneys?

17. What is the cause of urea in the blood?

18. Explain "nitrogenous equilibrium."

19. Why does one lose flesh during sickness?

20. How important is the work of the kidneys?

21. How does a cold affect the kidneys?

22. What is Bright's disease? What may cause it?

23. Explain "fatty degeneration" of the kidneys.

24. In what other ways does alcohol have a bad effect on the kidneys?

25. Why does the whole body suffer when the kidneys do not act?

CHAPTER XV

THE NERVOUS SYSTEM

The need of a controlling organ.—A number of different systems and organs have already been explained. Some are concerned in the movements of the body. Some take in and digest the food. Some distribute food and oxygen to the cells. Others rid the body of waste and impurities, and numerous others still are at work in one way or another for the welfare of the whole body.

Each organ must work in harmony with all the others, or it itself must soon suffer. For example, the tissues of the hands and arms need food; but, although the hands be loaded with the best kind of food, the tissues cannot get it until it is properly prepared by several other organs. The hand carries the food to the mouth; there it is masticated and mixed with saliva; then it is swallowed, and digested in the stomach and intestines: thence it passes over into the current of blood, and is distributed to the cells of the body. Thus the hands, by which the first act of this process was accomplished, are dependent on the organs of digestion, and the organs of digestion depend on the hands to bring food within their reach.

In a similar way each organ must rely upon the cooperation of the others, and the failure of any one important organ will result in the destruction of all.

From this it is plain that there must be one organ, or a collection of them, which shall have a controlling and directing influence upon the others, and which shall not only cause all parts to work in harmony, but also in proportion to the demands of the body at different times.

This important function is performed by the *nervous system.*

An organized body of men.—The human body may be considered as a number of units, each with a different function and all working together as an organized body. The relation of these various units may be made clearer by a comparison with a number of men who bind themselves together in an organized body for the accomplishment of a definite purpose. In such an organization a variety of different kinds of work must be done, and each man selects the kind which he can do best and does that only. Each member knows that his success depends on the success of the whole organization, but however good his individual work may be, his efforts may not be effective unless there is some way to direct his work in accordance with what is being done by the other members. So, in such an organization, a president is always selected, and it is his business to so direct the work of each that the general results may be most effective.

Heads of departments may also be appointed, and they may look after many matters of detail without reporting them to the president. Each man may after a time become so expert in his work that he can be trusted to continue it without constant direction.

Whenever one member of the organization fails to do his part or fails to work in harmony with the others, then the president must be notified and the matter adjusted, or the organization will break down.

All the relations just pointed out between the president and the other members of the organization are similar to those between the nervous system and the other organs of the body.

The nervous system.—The *nervous* system is composed of *nerve-centres, nerves,* and *special organs at the ends of nerves.* The nerve-centres are the *brain,* the *spinal cord,* and *ganglia.* The nerves all originate in the nerve-centres and extend out to the parts to which impulses are to be sent or from which impulses are to be received.

There is but one great nervous system, with centres here and there, and nerve-trunks and nerve-fibres ramifying to every part of the body, the whole system being more or less intimately joined together. But, because of certain differences in character and function, the system is divided into two parts. The first is called the *cerebrospinal* or *central nervous system,* and includes the *brain,* the *spinal cord,* and the *nerves* leading out from them.

The second is called the *Sympathetic,* or *Ganglionic, nervous system,* and includes numerous small nerve-centres called ganglia, and the nerves which issue from them. The sympathetic system is chiefly concerned with the involuntary movements of the body, such as those involved in digestion, circulation, and respiration.

The nerve-cell.—Nerve-cells, like other cells, are composed of minute masses of protoplasm containing a nucleus and a nucleolus. A very noticeable characteristic of a nerve-cell is its tending to send off many processes from the cell-body. Part of the processes are short, and soon divide into numerous fine branches within the gray matter of the nerve-centres. These branches are called *dendrites* because they resemble, in form, the branches of a tree.

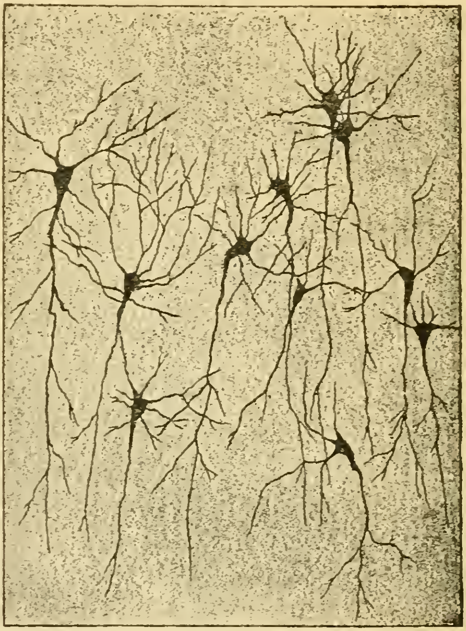

FIG. 106.—Neurons from the gray matter of the cerebrum. Cell-body, dendrites, and short portion of the axis-cylinder are shown. A microphotograph.

One process of the cell, usually much longer than the others, is called the *axis-cylinder*. It may extend out as far as two or three feet from the body of the cell. The axis-cylinder is a fine thread of protoplasm continuous with the cell material. The cell-body, the dendrites, and the axis-cylinder with its sheath and special endings all constitute one cell. This cell is as much alive as any of the one-celled animals described in the first chapter of this book. The processes of nerve-cells do not have movement as in the case of the amœba; but if the axis-cylinder of a nerve-cell be severed, that part of it which is thus deprived of connection with the cell-body and the nucleus will deteriorate and pass away.

The unusual extension of a fine thread of the cell material is the one thing about a nerve-cell which makes it so different from the other cells, and also makes it possible for nervous matter to exercise a controlling and directing influence over other cells.

The unit of the nervous system, the neuron.— Such a cell as we have just described is called a *neuron*. The neuron is the unit of the nervous system. The whole nervous system is a collection of a vast number of these units.

Since the axis-cylinder is a very delicate thread of protoplasm, it is protected by one or more membranes which surround it. Nearly all the axis-cylinders of the cells in the central nervous system have two coverings, as shown in Figs. 107 and 108. The first, called the *medullary sheath*, lies next to the axis-cylinder and consists of a white, oily substance. It is this sheath which gives to many nerves their pure white appearance. Outside of this is a thin elastic sheath called the *neurilemma*.

The medullary sheath is broken at intervals of about

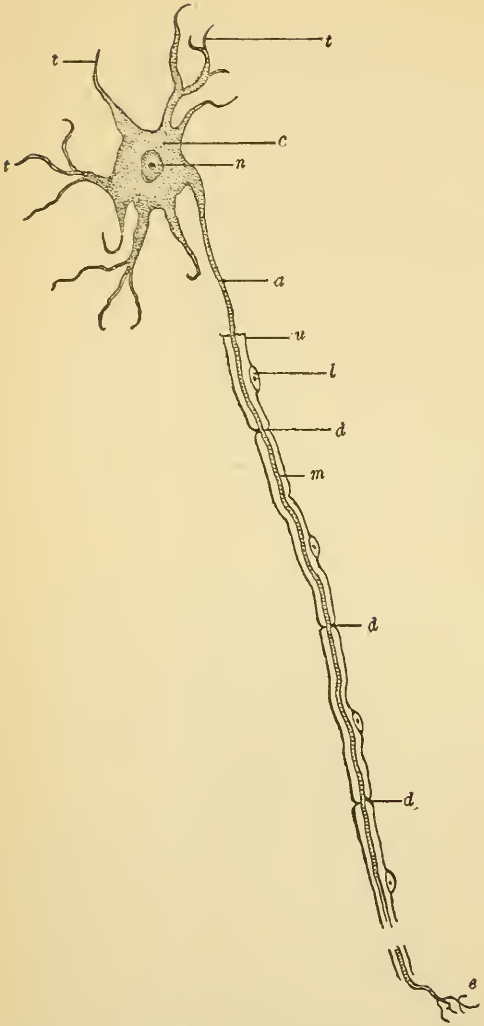

FIG. 107.—Diagram of a neuron. *c*, body of cell; *n*, nucleus; *t*, dendrites; *a*, axis-cylinder; *m*, medullary sheath (the white matter); *u*, neurilemma; *l*, nucleus of the neurilemma; *d*, nodes; *e*, endings.

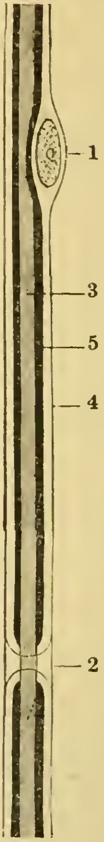

FIG. 108.—A medullated nerve-fibre, treated with osmic acid, and highly magnified. 1, its nucleus; 2, node; 3, the axis-cylinder; 4, membranous sheath of the internode; 5, medullary sheath (the thick black line).

$\frac{1}{25}$ of an inch by *nodes*. The neurilemma is continuous throughout the whole length of the nerve-fibre, and in it are embedded nuclei, one in each internode.

Fibres which are covered by both these sheaths are called *medullated nerve-fibres*, and such are always white.

Other fibres, chiefly those of the sympathetic nervous system, have no medullary sheath, and so are gray in color. These are called non-medullated nerve-fibres.

Nervous tissue.—Nerve tissue is composed of gray and white matter. The gray is the essential part of the system and is composed of the protoplasm of the cell bodies and the axis-cylinder. Wherever a number of cells are clustered together, the matter is gray, as in the brain, the spinal cord, and the ganglia.

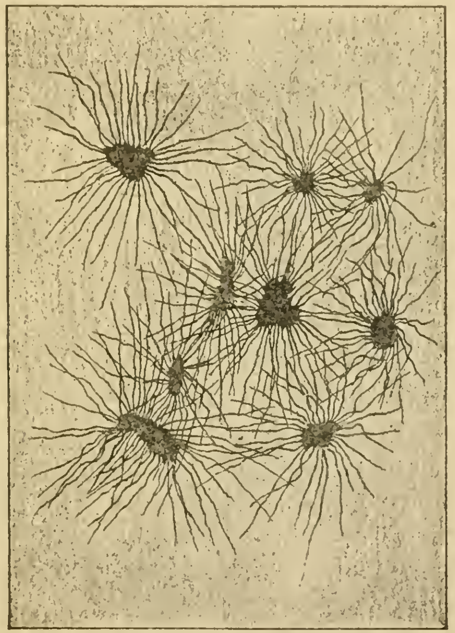

FIG. 109.—Neuroglia cells.

The white matter is composed of nerve-fibres, the whiteness being due to the medullary sheath around the axis-cylinder.

Both the gray and the white matter are supported and held together by the ordinary connective tissue, and also by another tissue called *neuroglia*. Neuroglia is peculiar to the nervous system. A few of its cells are represented in Fig. 109.

The brain.—The brain is the large nerve-centre of the body. It is enclosed within the bony walls of the cranium and is surrounded by three membranes. The outer membrane is called the *dura mater*. It lies next to the inner surface of the skull. The inner membrane, called the *pia mater*, adheres closely to the surface of the brain, passing in and out through all of its folds.

Between the two is the *arachnoid* (like a spider's web), so called because it is transparent and very thin. It is transparent, however, only in the sense that lace or a spider's web is transparent. It invests the whole surface of the brain, but does not follow the pia mater into the folds. Spaces between the arachnoid and the pia mater are filled with cerebrospinal fluid. This fluid is nearly pure water, and its purpose seems to be to protect the brain in case of sudden jars or concussions.

The pia mater is a very vascular membrane,—that is, it contains numerous blood-vessels for the supply of nourishment to the brain.

The three membranes are together called the *meninges*, and when they become inflamed the disease is known as *cerebrospinal meningitis.*

The human brain is larger, in proportion to the size of the body, than that of any other animal. Its average weight is a little more than three pounds. The weight of the brain of Cuvier, the French naturalist, was 66 ounces; that of Webster, the American orator, 63½ ounces; of Byron, the English poet, 64 ounces; of Gauss, the mathematician, 53 ounces. The brains of some intelligent men are less than the average in weight, and those of some idiots much heavier.

Divisions of the brain.—The brain is divided into several parts which differ in function and composition.

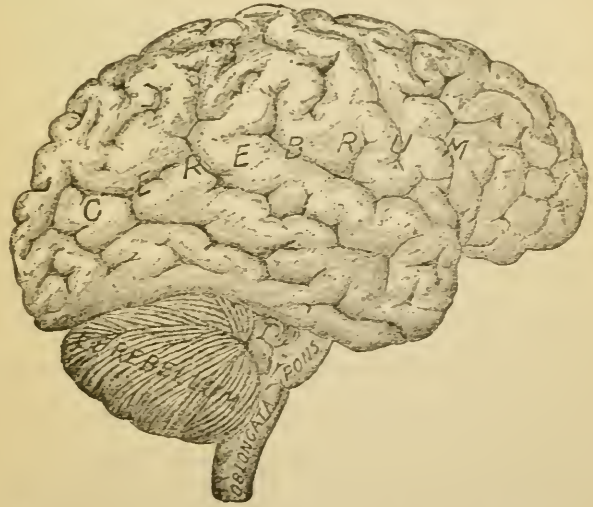

FIG. 110.—The brain as seen from the right side.

The most important parts are the *cerebrum*, the *cerebellum*, the *pons*, and the *medulla oblongata*. The cerebrum is the most essential part of the human brain, and is so called from the Latin word *cerebrum*, which means brain. Cerebellum is the diminutive of cerebrum and means *little brain.* Pons is a Latin word meaning *bridge.* Medulla means *marrow.*

The cerebrum.—The cerebrum occupies the whole upper portion of the cavity of the cranium. It is the brain proper, the other parts being more or less only aids. By weight the cerebrum constitutes about two-thirds of the whole brain.

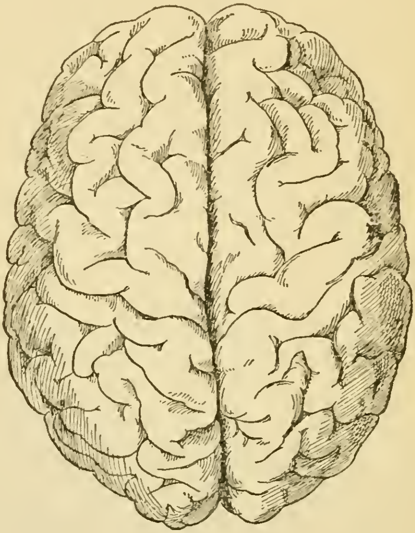

Fig. 111.—Top of cerebrum showing median fissure and convolutions.

A median fissure, extending from front to back, divides the cerebrum into the *right* and *left hemispheres.* (Fig. 111.) The two hemispheres are connected by a broad band of nerve-fibres called the *corpus callosum*, shown in Fig. 112.

Other fissures, irregular in outline and not so deep as the *median*, divide the hemispheres into lobes, which are given names in accordance with the names of the bones of the skull beneath which they lie.

Thus there are the *frontal*, the *parietal*, the *temporal*, and the *occipital* lobes.

The whole surface of the cerebrum is covered with gray matter to a depth of from one-sixth to one-twelfth of an inch. It is called the cortex of the cerebrum.

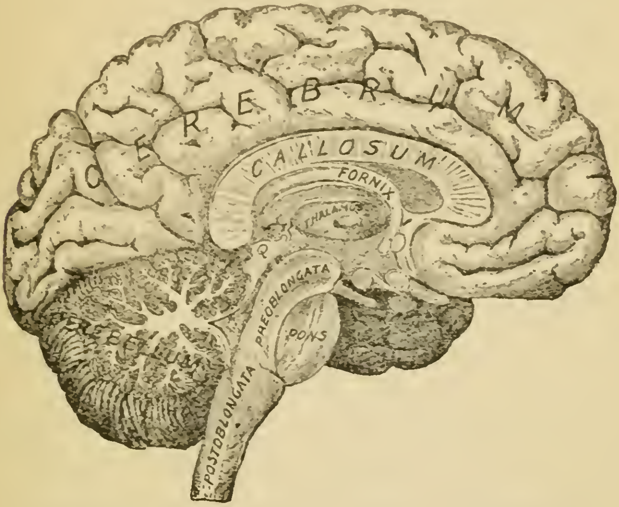

FIG. 112.—Cross-section of brain. Left half.

This matter is composed of the cell-bodies, their supporting tissue, and the blood-vessels concerned in their nutrition. Beneath the gray is the white matter, which is composed of the medullated nerve-fibres leading from or to the cells.

On the surface of the cerebrum are numerous deep convolutions or folds, which afford a large surface for the gray matter. The number and depth of the convolutions are the chief distinguishing marks between the brain of man and that of the lower animals, and also between that of the higher and lower races of men.

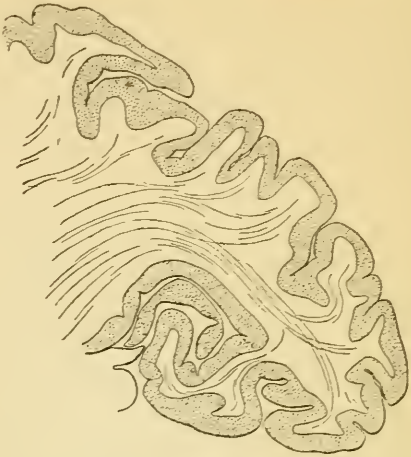

Fig. 113.—A portion of a horizontal section of a cerebral hemisphere, showing convolutions.

The cerebellum.—The cerebellum—the lesser brain—constitutes about one-eighth of the whole brain, and so is called the lesser brain. It lies beneath the posterior part of the cerebrum, as shown in Fig. 110. It is composed of gray and white matter, the gray being arranged in parallel ridges.

A cross-section of the cerebellum shows that the white matter enters each of its hemispheres as a trunk, and by numerous branches is distributed to all parts of the surface. (Fig. 112.) From this appearance the cerebellum has been called the tree of life.

The pons.—The pons is situated below the cerebrum and in front of the cerebellum. It is composed of both gray and white matter, and is about one inch long and a little more in thickness. Nerves from the spinal cord pass up through it to the cerebrum and cerebellum, and transverse fibres pass through it from one side of the cerebellum to the other. Thus the pons serves as a bridge by means of which communication can be made from one part of the nervous system to another.

The medulla oblongata.—The medulla oblongata is that part of the upper end of the spinal cord enclosed within the skull. It is about one and a quarter inches in length and about one inch through its thickest part. A fissure on both its anterior and posterior sides divides it into two equal parts. Both the gray and the white matter are found in the medulla, the gray being collected into groups which are more or less independent of each other, and which are the origin of some of the most important nerves.

Nearly all the fibres of the spinal cord cross over, in the medulla, to the other side, and, continuing on their way, make connection with the cerebrum and cerebellum. Thus the nerves from the right hemispheres of the brain are distributed to the left side of the body, and those from the left hemispheres to the right side.

Nerves.—The neuron has already been described. The axis-cylinder with its protecting sheaths is a nerve-fibre. A nerve is simply a number of nerve-fibres running side by side and bound together by connective tissue, in which are blood-vessels that convey nourishment to the nerve tissue.

Around the whole bundle of fibres is another sheath called the *perineurium.*

The nerve-fibres lie close together in a nerve, but each is independent of the others throughout its whole course.

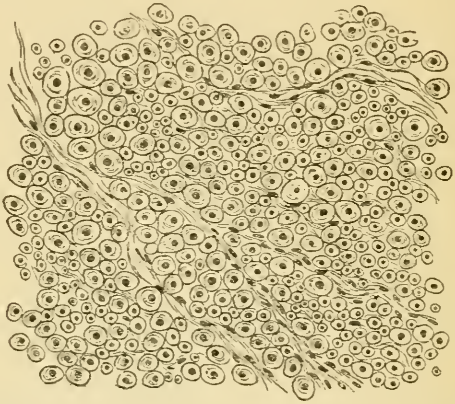

Fig. 114.—Portion of a cross-section of a nerve showing the ends of nerve-fibres. A microphotograph.

Whatever communication there is from one fibre to another, it does not appear to be along any kind of connecting fibre.

Nerves are smooth, white, shining cords which vary in size from those scarcely visible by the naked eye to the great sciatic nerve, which is about one-half inch wide and one-sixth inch thick, and extends from the lower end of the spinal cord down to the toes, sending off some fibres along its whole course, and growing less and less in size as it descends.

A nerve may be compared to a cable such as is used in a telephone system, where several hundred copper wires are encased in a lead tube. Each wire corresponds to the axis-cylinder of a nerve-fibre. Around each wire is a loose wrapping of paper. corresponding to the sheaths about the axis-cylinder. Around the whole bundle of wires is the lead tube, which corresponds to the perineurium of the nerve.

The copper wires serve only as conductors along which electricity may flow from a battery or other source of electricity to a machine or device which it operates at the other end.

Nerve-fibres, also, are only paths along which impulses travel from a nerve-centre to the part of the body which they stimulate. There is this difference, however, between an electric current passing over a wire and an impulse passing over a nerve,—the whole of the energy which operates a telegraph. telephone, or motor passes over the wire, while in a nerve only enough energy passes to stimulate to activity the potential energy already stored in the parts to which the nerves are distributed.

The illustration is more nearly true in the case where, by pressure of an electric button, a slight current of electricity is made to operate a device which opens a valve and admits steam to the engines, which in turn operate the machinery of a factory or exposition.

Efferent and afferent nerves.—All nerve-fibres appear to be alike in structure, but experiment shows that there are two kinds, at least as far as their functions are concerned. One kind conducts impulses out from nerve-centres, and so are called *efferent* or *motor* fibres. Another kind conducts impulses towards the nerve-centres and are called *afferent* or *sensory* nerve-fibres.

Efferent or motor impulses stimulate the muscles, glands, or other parts of the body to activity.

Afferent or sensory impulses keep the nerve-centres informed in regard to the condition of the body and its relation to other objects.

The cranial nerves.—Twelve pairs of nerves arise in the brain and pass out through openings in the cranium to the eyes, the ears, the mouth, the nose, and other important organs of the body. They are called *cranial nerves.*

The first are the nerves of the sense of smell. They are called *olfactory* nerves, and run from the nostrils to the base of the cerebrum.

The second are the *optic* nerves, or nerves of sight. They extend from the eyeballs to the base of the cerebrum. Both the first and the second pairs are purely sensory.

The third, fourth, and sixth pairs are motor nerves which run to the muscles that move the eyeballs.

The fifth pair are both motor and sensory, and are distributed to various portions of the face.

The seventh pair are distributed to the muscles of the face and scalp. They arise from the medulla oblongata, as do all the nerves of the last six pairs.

The eighth are the *auditory* nerves, or nerves of hearing. They are purely sensory.

The ninth are the *gustatory* nerves, or nerves of taste, and also the motor nerves of the pharynx.

The tenth pair extends farther from the brain than any other of the twelve pairs. They are called the *pneumogastric* nerves because of their important functions in relation to the lungs and stomach. They are also called the *vagi,* or wandering nerves, because they are distributed to so many organs. Branches of these important nerves are distributed directly to the pharynx, the œsophagus, and stomach, the larynx, trachea, and lungs, and indirectly, through the sympathetic nerves, to the heart, liver, pancreas, spleen, kidneys, small intestines, and large blood-vessels.

The eleventh pair are distributed to the muscles of the neck, and the twelfth pair to the muscles of the tongue. Nerve-fibres from the cells of the brain are distributed not only to the other parts of the body, but connection is made from one hemisphere of the cerebrum to the other by numerous fibres through the corpus callosum, and numerous other fibres connect the lobes and convolutions of the cerebrum with each other.

The spinal cord.—The spinal cord is a bundle of nerve-fibres enclosing an axis of gray matter composed of nerve-cells. It is about eighteen inches long in the adult, and extends from the large opening, the *foramen magnum* in the occipital bone, down to the lower part of the body of the first lumbar vertebra.

The spinal foramina of the vertebræ form the spinal canal within which the spinal cord lies.

The cord is surrounded by three membranes, the *dura mater*, the *arachnoid*, and the *pia mater*, all of which are continuations of membranes of the same names, already described as coverings of the brain.

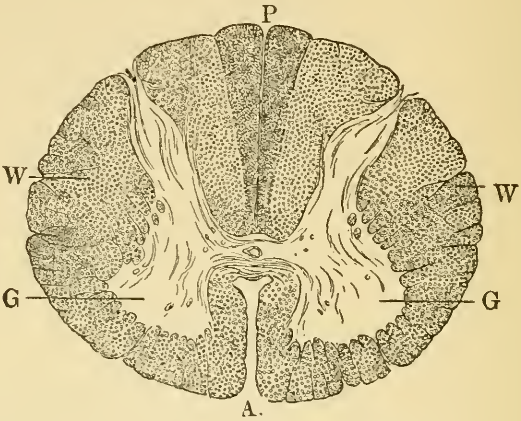

Fig. 115.—Diagram of cross-section of spinal cord. *A*, anterior fissure; *P*, posterior fissure; *G*, gray matter; *W*, white matter. The small circle at the centre is a cross-section of a minute canal which runs the whole length of the cord.

The spinal cord is about one-half inch in diameter, being a little thicker from side to side than from front to back.

Two fissures run the whole length of the cord, dividing it into two equal parts. The one in front is called the *anterior* or *ventral fissure*, and the one behind is called the *posterior* or *dorsal fissure.* The anterior fissure is wider and not quite so deep as the posterior.

A *cross-section* shows that the cord is composed of white and gray matter, the white being on the outside and the gray in the centre. This arrangement, as we have seen, is just the opposite of that in the brain.

The white matter is composed chiefly of medullated nerve-fibres running up and down the cord, while the gray matter is composed chiefly of nerve-cells. The two sides of the cord are connected, as shown in Fig. 115, by an isthmus of white and gray matter, giving to the gray a resemblance to the letter H. The anterior horns of the gray matter are blunt, and do not come very close to the surface of the cord, while the posterior ones are pointed, and reach almost to the surface.

In the centre of the isthmus, in the Fig., is seen a small circle. This is a cross-section of a small tube which runs the whole length of the cord, and opens above into cavities called ventricles in the white matter of the brain.

Spinal nerves.—Thirty-one pairs of spinal nerves issue from the cord and pass out between the vertebræ to nearly all parts of the body. On each side of the anterior fissure are two shallow grooves, and on each side of the posterior fissure are two similar grooves. From these grooves the rootlets of the nerves spring in a close longitudinal row, as may be seen in Figs. 116 and 117. A number of these rootlets collected together constitute a spinal nerve. Those that spring from the anterior part

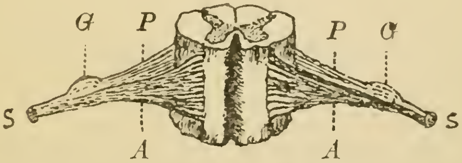

Fig. 116.—A piece of spinal cord. *A*, *A*, anterior, motor, or efferent nerve-roots; *P*, *P*, posterior, sensory, or afferent nerve-roots; *G*, *G*, ganglia on posterior roots; *S*, *S*, beginning of spinal nerves.

of the cord, on each side of the fissure, are motor nerves. Those which appear to originate on the posterior part on each side, are sensory nerves. The motor and sensory nerves from the same half of the cord soon unite into one nerve, the two kinds of nerve-fibres being bound together in the same bundle, and yet remaining independent of each other throughout their whole course.

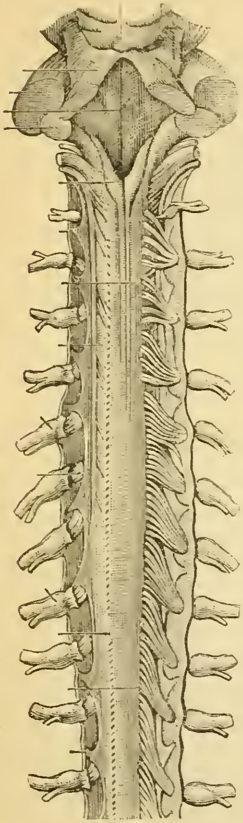
Fig. 117. — Posterior view of the upper section of spinal cord, showing the eight cervical nerves.

On the posterior roots, just before they unite with the anterior ones, is an enlargement, or knot, called a spinal ganglion. One of these is found on each of the posterior nerve-roots. These are small collections of nerve-cells with special and important functions.

The roots of the anterior, or motor, fibres arise from the cells in the anterior horn of the gray matter, and an impulse from that source moves out on the different fibres.

The sensory fibres arise from the cells of the spinal ganglia, as shown in Fig. 118. These fibres divide into two, a short distance from the cell,— one branch running out to the sensory region, as the skin, and the other branch joining the spinal cord and passing up through the white matter to the brain. Here and there along its ascent fine branches are given off which arborize about the cells in the anterior horn of the gray matter. That is, the fibre at its end divides into fine branches, which mingle with the dendrites of the motor cell, much as the branches of one tree may mingle with those of another when the trees stand close together.

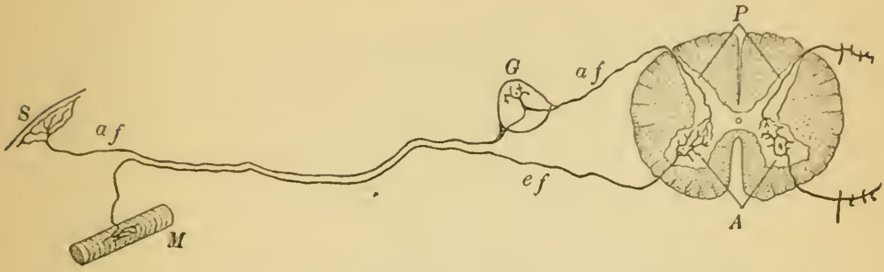

FIG. 118.—Diagram showing the origin and relation of afferent and efferent nerves. *S*, skin; *G*, ganglion; *P*, posterior horns; *M*, muscle; *af*, afferent nerve; *ef*, efferent nerve; *A*, anterior horns.

Nerve endings.—As already explained, the neuron is a cell which is peculiar in that it may send out a very long process of its own material. The cell-body and its nucleus are the central parts of the neuron; the axis-cylinder process is the line of communication between the cell-body and the organ to which the neuron is attached; and the *nerve ending* is a special arrangement by which a nervous impulse may be readily communicated to the cells of other tissues, or by which an outside stimulus, such as light, sound, and touch, may be received with distinctness and intensity.

Not every neuron, however, is supplied with a special ending. A single nervous impulse may be transmitted over several neurons to its destination. As shown in diagram (Fig. 119), the impulse may start from A and travel to B, thence on the next neuron to C. and finally reach the ending in the muscle at M.

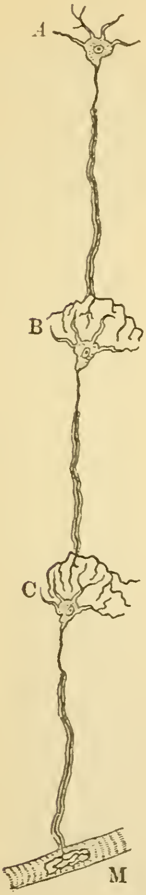

FIG. 119.—Diagram showing method by which one neuron may communicate with another.

Motor end plates.—At the termination of nerves which are distributed to muscles, the protoplasm of the axis-cylinder appears to be poured out on the muscle-fibre for a distance in all directions, as shown in Fig. 120. This is called the end plate of the nerve.

An end plate is attached to each muscle-fibre. near its middle.

The nerve-fibre pierces the wall of the muscle-fibre, the neurilemma being joined to the sarcolemma, and the axis-cylinder of the nerve being joined to the protoplasmic contents of the muscle-cell. Thus, a ner-

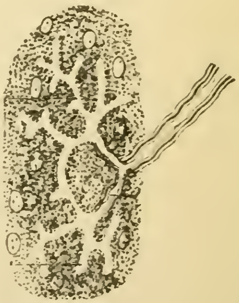

FIG. 120.—End plate of a motor nerve-fibre.

vous impulse may start in a nerve-centre, as in the brain or spinal cord, and be conducted along a nerve to the end plate, and thence to the fibres of muscle, causing them to contract.

Endings of sensory nerves.—In case of a sensory nerve, the stimulus is applied at the end and the resulting impulse travels in to the nerve-centre.

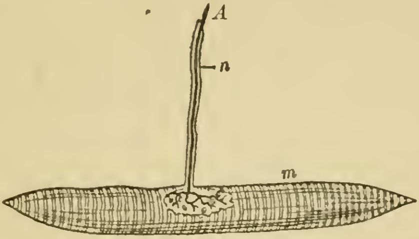

FIG. 121.—Diagram showing connection of a nerve-fibre to a cell of muscle. A, axis-cylinder of nerve ; n, neurilemma ; m, cell of muscle.

The office of this set of nerves is to keep the nerve-centres informed in regard to the *condition* of the body and the body's *relation* to outside objects. Thus, when any wound is received or any organ is diseased, the mind is informed by impulses conveyed on the sensory nerves. The same set of nerves also convey sensations of heat and cold and pressure.

One pair of this kind of nerves has such delicate endings—the eyes—that even waves of ether can start in them an impulse which produces the sensation of light. Another pair has the ears for nerve endings, and waves of air can start in them an impulse which results in the sensation of sound.

There are five special sensory nerve endings producing five special senses,—*seeing*, *hearing*, *feeling*, *tasting*, and *smelling*. These are more fully described in a separate chapter.

Other nerves.—Nerves have been classified as *motor* and *sensory* because these are their chief functions. But nerves perform other functions also.

Secretion and excretion are vital operations and are performed by living cells, which are grouped together in a form which we have called a gland. Nerve-fibres are distributed to each cell of a gland, and the stimulus which comes to them over the nerves regulates the activity of the gland. If such a nerve be severed, the gland will become inactive.

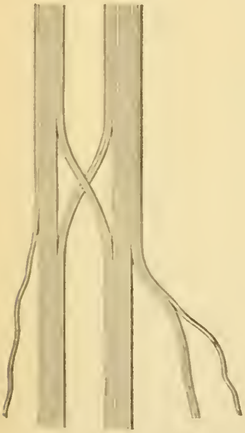

FIG. 122. — Mode of branching of nerve-fibres.

A nerve plexus.—A nerve plexus is a point where many nerves come close together and where fibres branch off from one nerve and continue their way in another nerve.

Nerve-fibres do not form a network, like blood capillaries, but, as shown in Fig. 122, fibres leave one bundle and join another. Numerous branches of this kind occur in the plexuses.

The nerve which comes from a plexus may thus be put in communication with many nerve-centres. In this way the parts of the body to which such nerves are distributed, for example, the legs, are capable of a great variety of movements.

Numerous plexuses, some large and some small, are found throughout the nervous system. The chief ones are found in the neck, the regions of the pelvis, and associated with the sympathetic system in the cavities of the thorax and abdomen.

The sympathetic nervous system.—The sympathetic nervous system is chiefly concerned in the stimulation and control of the involuntary processes.

It is called sympathetic because of the close relation or sympathy which these nerves establish between many vital organs of the body. For example, increased muscular effort calls for more blood, the arteries relax, and the heart responds by beating faster. This calls for more oxygen, and breathing is hastened. The product of this increased combustion must be cared for by an increased activity of the excretory glands.

Thus, by means of the connecting nerves, one organ is made to work in harmony with another.

The sympathetic system consists of *ganglia*, *nerves*, and *plexuses*. The chief ganglia are forty-nine in number and are arranged in two rows, one on each side of the spinal column and a little to the front of it. Each ganglion is connected by a nerve to the one above it and to the one below it, giving to the whole the appearance of two chains hung from the base of the cranium, with their lower ends connected at the coccyx. Thus, there are twenty-four ganglia on each side and one at the bottom midway between. and to which the lower ends of the two chains are attached.

The nerves of the sympathetic system are, for the most part, non-medullated, and so are finer and of a grayish color.

Along with these nerves are mingled many branches of the spinal and cranial nerves, so that the whole nervous system is intimately connected.

The sympathetic nerves are distributed to the viscera of the thorax and abdomen, to the blood-vessels, and to the lymphatics.

In front of the chains of ganglia are three great plexuses of nerves containing numerous smaller ganglia. The one in the thorax is called the *cardiac plexus.* The one in the abdomen is called the *solar plexus.* It is just back of the stomach and has smaller plexuses radiating from it, the whole resembling somewhat the sun and its rays, and hence its name. The one in the pelvis is called the *hypogastric plexus.*

QUESTIONS FOR REVIEW.

1. Why does the body need a controlling organ? Illustrate.
2. Compare the body as an organism with an organized body of men.
3. Of what parts is the nervous system composed?
4. What three kinds of nerve-centres?
5. What are the two great nervous systems? Of what is each composed?
6. Describe a nerve-cell.
7. What is the unit of the nervous system?
8. Describe the *axis-cylinder* and its sheaths.
9. What makes a nerve-fibre white?
10. How does the gray differ from the white matter of the nervous system?

11. What is *neuroglia?*

12. What is the *brain?* Describe its coverings.

13. What is meant by "the *pia mater* is a vascular membrane"?

14. What is *cerebrospinal meningitis?*

15. What is the weight of the human brain?

16. What are the principal divisions of the brain?

17. Describe the *cerebrum* as to its fissures, hemispheres, lobes, convolutions, and cortex.

18. Describe the structure of the *cerebellum.*

19. Describe the *pons.*

20. What is the *medulla oblongata,* and of what is it composed?

21. Describe the structure of a nerve.

22. How large are nerves?

23. Compare a nerve to a telephone cable.

24. What are the two kinds of nerves, and how do they differ?

25. How many pairs of *cranial nerves?* To what parts of the body are they chiefly distributed?

26. Describe the *pneumogastric* nerves.

27. How is the spinal cord protected?

28. Make a drawing and explain the appearance of a cross-section of the spinal cord.

29. How many spinal nerves?

30. What are the roots of spinal nerves, and what two kinds?

31. Which roots have ganglia?

32. Explain how the two kinds of nerves connect with the spinal cord.

33. What are *nerve endings?*

34. Describe a *motor end plate.*

35. What kind of endings on the sensory nerves?

36. Explain a *nerve plexus.*

37. In what way does one nerve branch to another?

38. Why is the *sympathetic system* so called?

39. Of what is the *sympathetic system* composed?

40. Describe the *solar plexus.*

CHAPTER XVI

PHYSIOLOGY OF THE NERVOUS SYSTEM.

SOME functions of the nervous system have already been alluded to in the preceding chapter to make plainer the anatomy of the part described. This chapter will be devoted entirely to a brief description of some of the fundamental functions of the system as far as known.

Little by little many important facts about nerve-centres and nerves have been discovered, but as yet much is unknown both about their anatomy and their physiology. It is known, for example, that the mind is in some way intimately associated with the brain; but we have not even a plausible theory as to the nature of the association. It is known that some kind of an impulse passes from cells over nerves; but nothing is known as to the nature of the impulse. It is known that an impulse may be transmitted from one neuron to another; but it is not known how this is accomplished.

All such facts will doubtless be satisfactorily explained when the related sciences have advanced far enough to make such things intelligible.

Four functions of nerve-centres.—Collections of nerve-cells, forming nerve-centres, are the essential parts of the nervous system, the nerves being simply the carriers of nervous impulses.

The functions of these centres may be classified as four kinds. (1) *They are receivers of impulses brought to them over afferent nerves.* The effect of the impulse is a sensation of which the mind may or may not become conscious. (2) *They are the origin of impulses which cause a contraction of muscles.* Thus, all movement of the body is under the control of the nerve-centres. (3) *They direct and control nutrition, secretion, excretion, and distribution.* (4) *The highest function of any nerve-centre is that of thinking, knowing, feeling, willing, and remembering, all of which are in some way connected with the cerebrum.* These mental operations are functions of the cerebrum only in the sense that mind operates through the matter of that centre.

Function of the cerebrum.—It has been estimated that the gray matter—the cortex of the cerebrum—contains over 9,000,000,000 nerve-cells. The functions of this great nerve-centre are the most important performed by a human being, and are the distinguishing marks between man and all other animals.

The cerebrum is the *centre for all mental operations.* It is there that we are *conscious of our existence* and of what we are doing. It is there that we *study*, *think*, *imagine*, and *remember*.

All such mental operations are probably accomplished by all the gray matter of the cerebrum working together. In the anatomy of the cerebrum it was explained that numerous fibres connected the hemispheres, lobes, and convolutions of the cerebrum. By means of these the cerebrum may act as a unit.

Localization of functions.—Two other great functions of the cerebrum are *volition* and *sensation*. These are more or less limited to certain areas of the cortex. For example, one area may be a centre for the movements of the arm, and another for movements of the leg. One area may receive sensory impulses from the eye and another from the ear. Thus there is a division of labor among the cells, each area performing a definite function peculiar to itself.

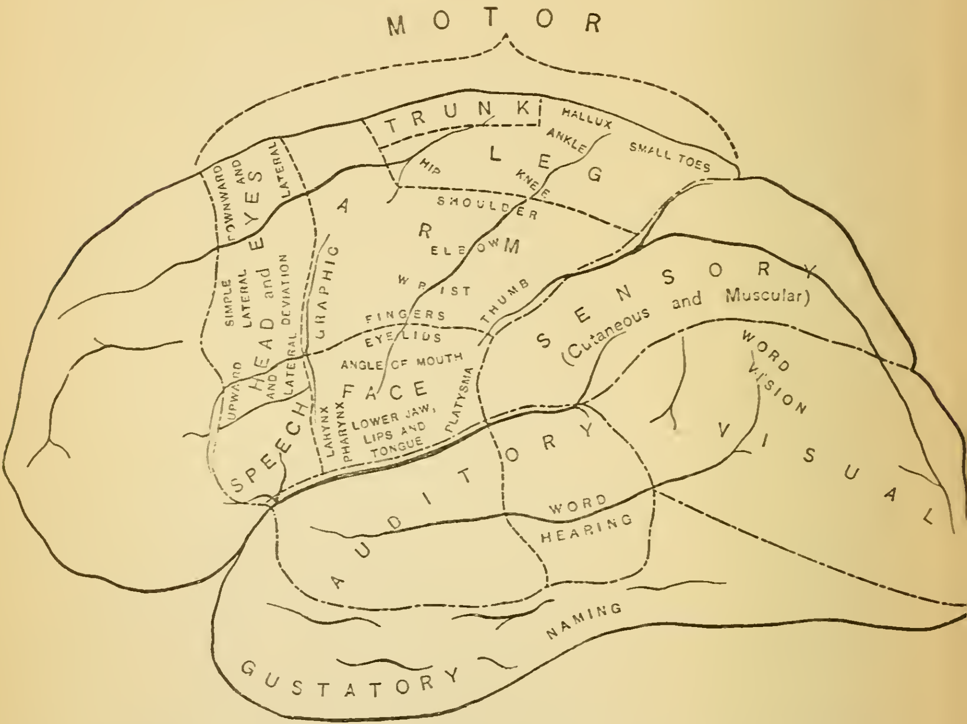
MOTOR
TRUNK
HALLUX
ANKLE
SMALL TOES
LEG
HIP
KNEE
SHOULDER
ARM
ELBOW
WRIST
THUMB
FINGERS
DOWNWARD AND LATERAL
EYES
HEAD and EYES
SIMPLE LATERAL DEVIATION
UPWARD AND LATERAL
GRAPHIC
EYE LIDS
ANGLE OF MOUTH
FACE
LOWER JAW, LIPS AND TONGUE
LARYNX
PHARYNX
PLATYSMA
SPEECH
SENSORY
(Cutaneous and Muscular)
WORD VISION
VISUAL
AUDITORY
WORD HEARING
NAMING
GUSTATORY

FIG. 123.—Diagram showing the location of the motor and sensory areas. It will be noticed that the motor areas are in the central region of the cortex, and the sensory areas are in the posterior parts.

By numerous experiments, many of these areas have been mapped out. If through accident the skull is made to press upon certain portions of the cortex, it is observed that some portion of the body loses sensation or the power of motion—that is, becomes paralyzed. Sometimes a blood-clot becomes lodged over certain parts of the brain, and similar results follow. In such cases, if the cause of the pressure be removed, the part of the body that was affected will regain its normal condition.

Experiments have also been made upon the monkey's brain, which most resembles the human, and when an electric stimulus is applied to various points on the cortex, it is observed that different parts of the body are caused to move. Thus, when one point is touched, the fingers will close. At other points the arms, legs, or toes will be affected.

In this way the cortex has been mapped out into motor areas, as represented in Fig. 123.

The sensory regions are not so definitely determined. The sensation of vision is located in the occipital lobe of the cerebrum, the region of hearing is just in front of it, and taste and smell are located in the temporal lobes.

The cerebrum as the controlling organ.—The muscles of the body may receive a stimulus from several different nerve-centres, but all voluntary acts have their origin in the cerebrum. *The cerebrum is the centre of all voluntary motion.*

Sensory impulses, also, may never reach the cerebrum, or may be unheeded there, but *all conscious sensation is in the cerebrum.*

While the cerebrum acts as a unit in the higher functions of thinking and knowing, each hemisphere exercises complete control over the opposite side of the body, and through the sympathetic system may even greatly modify the involuntary movements.

Impulses carried over a sensory nerve may produce a conscious sensation, and the motor nerves may then at once carry a stimulus to the muscles, and thus execute a volition. The sensation may, however, be stored in the memory and not acted upon for weeks or years. Man, in this respect, differs from animals, which are in most instances creatures of sudden impulse.

Intelligence and the size of the brain.—Other things being equal, intellectual power is proportional to the size of the brain. Size alone, however, is no proof of a superior intellect. Men whose brains were of average size have often shown themselves superior in thought to others who had a large head. The texture and area of the cortex of the cerebrum seem to have most to do with the character of a man's mental endowment.

Function of the cerebellum.—The function of the cerebellum, as far as known, is chiefly to harmonize and coördinate the various movements of the body. The act of balancing the body and retaining the proper position in standing or walking or performing any act in which many muscles are engaged is performed by the cerebellum. When this part of the brain is injured the sense of equilibrium is lost, and one will stagger like a drunken man when he attempts to walk. The cerebrum can still order any movement as before, but the muscles will not act in harmony, and so the execution of the movement will be extremely awkward.

Function of the pons.—As might be inferred from the anatomy of the pons, it is chiefly a passage-way for nerves from various parts of the nervous system. It contains, however, a considerable quantity of gray matter, and no doubt is the origin of some important functions besides being simply a medium of communication.

General functions of the medulla oblongata and the spinal cord.—Since the medulla is properly a continuation of the spinal cord, they have functions which are common to both. The first is *the transmission of impulses over the fibres of white matter to and from the brain.* These fibres cross in the medulla to opposite sides, so that if they be severed on the right side above the point of crossing, the left side of the body will be paralyzed. If they be severed on the right side below the point of crossing, the right side of the body will be paralyzed. Most of the motor impulses from the brain pass through the white matter of the medulla, spinal cord, and spinal nerves to the muscles, glands, and cells of the body. Along this same route, though on different fibres, many of the sensory impulses come to the brain.

The second important function, common to both, is *reflex action.*

The action is called reflex when a sensory impulse is sent in to a centre in the medulla or cord, and from that centre a motor impulse is sent out to a muscle or gland without the knowledge or action of the cerebrum. By reference to Fig. 118 the circuit of a reflex action can be seen. A sensation starting at the skin is conveyed by an afferent nerve to the cord, where a branch from the nerve communicates with cells in the anterior horn of the gray matter, and these cells send back a motor impulse on an efferent nerve to the muscle. Thus a reflex action is a short-cut from a sensory region to nerve-centre and back to muscle.

By reference to the illustration in the second paragraph of Chapter XV it can now be seen that these centres of reflex action correspond closely to the heads of departments in the organized body of men. In most of the ordinary matters no report is made to the president of the organization, but only to the head of the department, and he at once sends out the proper orders. If anything unusual happens, then a report is made to the head of the whole organization,—the president. In the same way all ordinary routine matters of the body are attended to by the reflex centres; but when anything arises which requires thought, deliberation, or choice, the whole matter is referred to the cerebrum.

The afferent nerve continues its way up the cord to the brain, so that the same impulse may produce conscious sensation, and additional motor impulses may be sent out by the overruling cerebrum.

Examples of reflex action.—A man whose spinal cord is broken or diseased in the dorsal region will still move his legs violently if the bottoms of his feet are tickled. The tickling could not produce any conscious sensation, for all connection with the cerebrum is severed. A centre in the lower part of the cord receives the sensory impulse from the foot and at once sends back on a motor fibre an impulse which causes the contraction of the muscles. It is evident from these facts that certain nerve-centres may receive and send out nervous impulses without the knowledge or interference of the brain.

Such action is of constant occurrence in the normal body. If the hand touch a hot object, it will almost instantly be pulled away. One will, even while unconscious in sleep, brush a fly from his face; and although such action is not a result of a conscious effort of the will, yet it is directed in accordance with a definite purpose.

The presence of food in the mouth, or even the sight of food, may cause an impulse to be sent out to the glands which secrete saliva or other digestive juices. Such action is purely reflex and requires no effort of the mind.

Special functions of the medulla.—The medulla contains some of the most important reflex centres. The whole brain above the medulla may be removed, and the animal so treated will continue to live, but without sensation or volition. Such an animal will continue his breathing in the ordinary manner, his heart will continue to beat, and other vital functions will be performed as before, but he will remain in one spot until he starves to death. If, however, he be touched, he will move. If food be placed on the back of his tongue, he will swallow. These are purely reflex actions.

If, now, the medulla be destroyed, death will follow immediately, for in the medulla is the "vital knot," or nerve-centre, which operates breathing. This centre is even stronger than the will itself, for, although we may voluntarily stop breathing for a time, yet it will soon begin in spite of any effort of the will.

In the medulla is another centre which regulates the beating of the heart, causing it to beat faster or more slowly as the need may be. Another important centre there is the vasomotor centre, which causes the walls of the arteries to contract or relax, thus regulating the supply of blood to various parts of the body. Still others are the sneezing, coughing, and vomiting centres.

The medulla is the great centre of those reflex actions upon which the maintenance of life depends.

The economy of life in reflex action.—If every sensory impulse had to go to the cerebrum, and every motor impulse had to come from it, the mind could do little else than attend to the ordinary routine matters of life, and would do that very poorly. It is much better, as nature has fixed it, to have certain centres which become expert in doing those things which are repeated again and again. In this way the mind is free to devote itself to a consideration of higher and more important matters. Thus a student can concentrate his whole mind upon the solution of a problem, and other nerve-centres will look after the breathing, digestion, excretion, and the flow of blood.

Not only is there economy of life in having reflex centres to perform the vital functions, but also many of the acts, which at first required a conscious effort, may and should become reflex. Those actions, which are repeated again and again through life, should be made automatic as completely as possible. Such actions as walking, writing, playing a musical instrument, proper forms of speech, dressing, and all actions which are constantly repeated in any occupation in which one is engaged, should be automatic.

Education of reflex centres.—Some of the reflex centres, especially those in the medulla, were born with us in full power of operation. These are indispensable to the maintenance of life. Many other centres in the cord and brain are capable of education.

The first efforts at walking require a close attention of the mind, but by repeated efforts the action becomes reflex and automatic. Then, when the motion of the legs is once started, the walking will be continued, though the mind be directed to other matters.

Writing at first is a laborious process, taking the full attention of the child, but later the hand makes the letters while the mind is attending to the thought.

The first attempt to play a violin is awkward, and the mind must attend every movement of the fingers, but by constant repetition the action becomes reflex, and thought can then be given to harmony and expression.

Even such matters as tying shoe-strings or a neck-tie become, by frequent repetition, purely automatic.

Habit.—Habit is an acquired disposition to act or think in a certain way. It may easily be inferred from what is said in the preceding paragraph that habit is formed by frequent repetition of the same act or thought.

A habit may be of the greatest advantage or disadvantage to its possessor.

The character and mode of action of the nervous system furnishes the basis for an explanation of the formation of habit.

Several repetitions of the same act, in response to any stimulus, will make it easier for that same stimulus to result in a similar act. For illustration, when a boy is being taught that he should lift his hat when he meets a lady, he may have to be reminded of the fact a number of times at first, but after many repetitions of the act he will perform it without any thought whenever the occasion arises.

One who has often wet his fingers or thumb in his mouth when he wished to turn the leaves of a book is quite sure to employ that method when he reads a paper or book before an audience.

The motor impulses come to act in certain grooves, as it were, and, unless the dominant cerebrum is able to overpower and direct these impulses in new channels, the habit becomes fixed.

Functions of nerves.—Nerves are the conductors of nervous impulses. While the nature of the impulse is not known, its various effects are doubtless due to the character of the organ which receives it, just as a current of electricity will produce sound in a telephone, light in an electric lamp, motion in a motor, or electrolysis in certain chemical compounds.

The various sensory organs receive stimuli from the outside, and the afferent nerves carry them to the nerve-centres.

The efferent nerves carry orders from the nerve-centres, and their effect may be a contraction of muscles, secretion of the glands, nutrition of the cells, or a regulation of the rapidity and frequency of muscular contraction, as in the heart.

Each fibre of a nerve has its own special work to do, and if it is disabled the other fibres near by cannot assume its work. If a small part of the liver or lungs should be injured, the remaining part can completely perform the functions of those organs; but if a single fibre of the optic nerve, for example, should be severed, a blind spot will be produced in the eye.

QUESTIONS FOR REVIEW.

1. Give four functions of nerve-centres.

2. What makes the cerebrum such an important centre?

3. In what part of the cerebrum do we think?

4. Name several mental operations that are performed in the cerebrum.

5. Explain what is meant by the localization of functions. How was this determined?

6. Give the locality of several motor areas in the cortex of the cerebrum. Also locate several sensory areas.

7. What is voluntary motion, and where is its centre?

8. Where do we become conscious of a sensation?

9. Why does an injury to the right side of the brain paralyze the left side of the body?

10. What is meant by saying that wild animals are creatures of sudden impulse?

11. What relation is there between the size of the brain and mental capacity?

12. What is the chief function of the cerebellum?

13. Of what use is the pons?

14. What two important functions are common to the medulla and the spinal cord?

15. Explain fully a reflex action.

16. Give several examples of reflex action.

17. Explain how centres of reflex action are like heads of departments in a large store.

18. Describe the important functions of the medulla.

19. What class of reflex actions are centred in the medulla?

20. State fully the advantage of reflex action.

21. How can reflex centres be educated?

22. What is a habit?

23. Explain how habits are formed.

CHAPTER XVII

HYGIENE OF THE NERVOUS SYSTEM

Nutrition of nervous tissue.—The brain, as well as other nervous tissue, is directly dependent on the food which we eat for its well-being and its ability to perform its functions.

It is not known just how nerve tissue appropriates its food, but it is clear that when the supply of food is inadequate, or the blood is for any reason impoverished or poisoned, the nerve tissue will suffer in common with the rest of the body.

This is a fundamental fact in considering the relation between a healthy body and a vigorous mind. All food must be properly prepared by the organs of digestion, secretion, and excretion, and then properly distributed by the organs of circulation before it is ready for assimilation by the nervous tissue or any other tissue. A healthy nervous tissue is then possible only when other organs of the body can supply to it good and sufficient nourishment. It is not necessary to a strong mind that the muscles be strong and that a man be able to perform heavy manual labor, but it is necessary that the other organs be able to perform their functions.

Expenditure of energy in nervous operations.—Every impulse sent out by a nerve-centre involves an expenditure of energy. Every thought which passes through the mind, and every mental effort in the solution of a problem or in pursuance of a line of thought, uses up some of the store of energy in the brain. The only source of this energy is the food which we eat and the air which we breathe. Just as a muscle becomes fatigued when its store of energy runs low, so a nerve-centre can work only when it has a stock of energy to expend.

The brain a favored organ.—All the other organs are helpless without the direction of the brain. Such actions as breathing and the beating of the heart will continue for a time without any directions from the cerebrum, but all voluntary action will cease, and the whole body, if left to itself, will soon be without food, and so without any store of energy to expend. The natural result is death, which in this case would simply mean that the store of energy had run out, and consequently no further activity could be possible.

For this reason every effort is made by the body to protect and keep strong the master organ,—the brain.

By referring again to the organized company of men which we have used for illustration, it is plain that the life and health of the president, if he is a good one, should be preserved for the sake of every other member of the organization. Much more so is this true of the brain, for no other organ can by any means be elected to its place.

So we find the brain well protected from any chance injury, and it also appears that the other organs will, when necessary, sacrifice some of their store of energy for the sustenance of the brain, acting, as it were. on the principle that if the brain should fail, all would fail with it.

Proper kind of food for the brain.—Much stress has sometimes been laid on the necessity of certain kinds of food for the support of particular tissues. One kind for the brain, another for the muscle or the bone, and so on. While this is true to some extent, yet it is fortunate that we do not at each meal have to determine the needs of the various tissues, and then make out a bill of fare to supply those needs.

Any good, mixed diet contains the elements necessary for the sustenance of the brain. Besides, we cannot conclude that because certain chemical compounds are found in a tissue. that therefore we should eat foods which contain those compounds; for the cells of the various organs are able to form many new chemical compounds from the food material.

The important matters to be considered are that the food be healthful for the whole body; that it be well masticated and digested; that it be distributed in the blood to points where it is needed; that it be completely oxidized; and, last, that the products of the oxidation be completely removed by excretion.

When all these are performed in a natural way, the brain will receive its proper nourishment without further attention on our part.

The supply of blood to the brain.—We have tried to emphasize the fact that every nervous impulse and every process of thinking involve an expenditure of energy which is obtained from food. The average brain constitutes only about one-fiftieth of the weight of the body, but about one-eighth of the blood is sent to it for its nourishment. The internal carotid artery, as seen in the figure, one on each side, passes in through the base of the cranium, and is distributed through the vascular pia mater to the brain-cells. If the blood

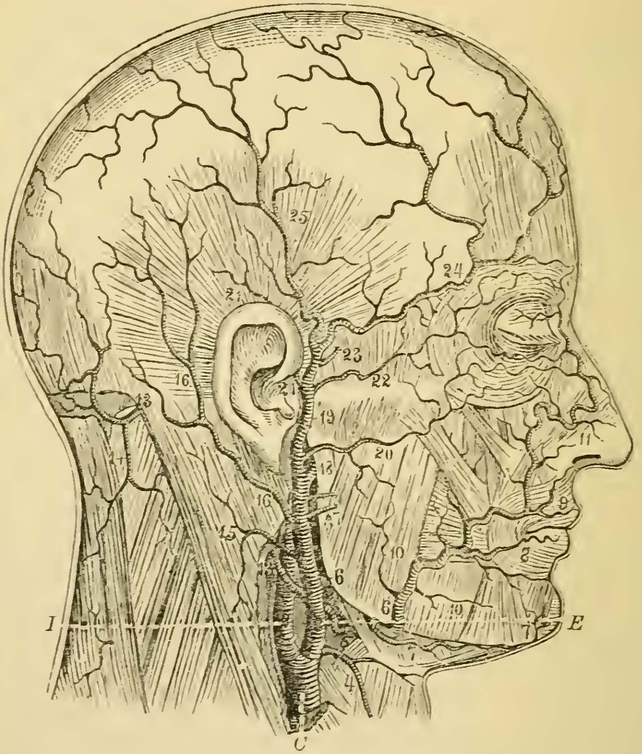

FIG. 124.—The carotid artery conducting blood to the head. *C*, right carotid; *I*, internal carotid; *E*, external carotid.

should be withdrawn, unconsciousness would result at once, and in a short time death.

This close dependence of mental action upon the blood supply makes it clear that the blood should be rich in those materials which are loaded with energy, and also free from alcohol, nicotine, opium, and all other substances that have an injurious effect upon the nervous tissue.

Brain fatigue.—A machine cannot give out any energy until it first receives it. That is, it cannot do any work until work is done upon it. A clock will not run until it is wound up. If you will transfer enough of your energy to a clock-spring to keep it running for eight days, the clock will come to rest at the end of that time only because the store of energy which it received from you has then been expended.

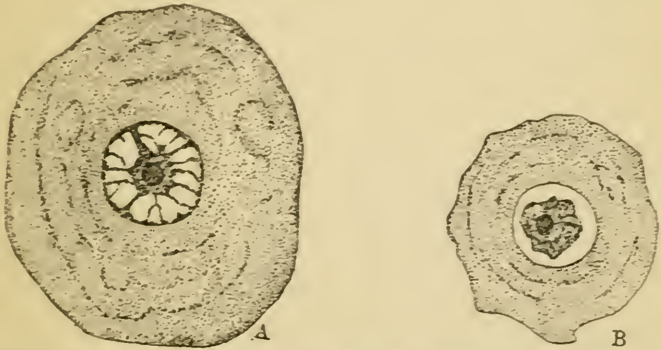

FIG. 125.—*A*, a cell stored with energy-yielding material; *B*, same cell fatigued after a period of work.

The cells of our bodies are little machines in this respect. They can convert energy which was in food into other forms, such as motion and heat, but they cannot expend any more than they receive. This is just as true of nerve-cells as of any cells of the body.

It is plain, then, that after cells have been at work for a time their store of energy will be expended, and the cells will become fatigued.

The condition of a fatigued cell can actually be observed by means of a microscope. As seen in Fig. 125, the cell at first is round and plump, but after a season of work it became jagged and shrivelled. The cell can now be stored again, and will then be able to do more work. Thus the cell is like the clock-spring, and if they are regularly re-stored with energy they will continue to run until worn out.

Need of sleep.—Cells may be receiving and expending energy at the same time, or they may rest and store up an excess of energy, which may be rapidly expended later.

Man and all animals are so constituted that periods of complete rest in sleep are absolutely necessary. Some organs of the body, as the muscles, may get partial rest by simply ceasing from work, but there is no complete rest, particularly for the brain, except in sound sleep.

The nature and cause of sleep are not known ; but it is known that during that time the fatigued and shrivelled cells gradually become round and full, and thus are ready for vigorous effort when the period of sleep has passed.

During sleep every organ of the body partially or completely suspends operation. All consciousness and all voluntary action cease completely in sound sleep. Even reflex action is slower in response to any stimulus. Breathing, beating of the heart, and excretion continue, but at a slower rate.

Sleep, then, is a period of complete rest, during which the cells constantly gain in energy-yielding material, and at the same time there is a minimum of expenditure of energy.

Amount of sleep necessary.—The amount of time that should be spent in sleep varies with age, occupation, temperament, and state of health. Eight hours is probably a fair average. Children need more than eight hours, and old people less. Most people take too little rather than too much sleep. This is especially true of active young men and women. Needed sleep that is lost can never be completely made up at a later date. The over-expenditure of energy is not a matter of much consequence, for energy is plentiful in the world; but it is a matter for most serious consideration that the machine—the cell or organ,—may thereby be injured so that its capacity for receiving and transmitting energy is thereafter lessened.

Vigorous mental exercise is conducive to strength of intellect. The more the mind is properly used the stronger it becomes, just as a proper exercise of muscle will result in its development. But there are limits beyond which either brain or muscle will be injured by further exercise. The limit is reached when the store of energy runs low and demands are made upon them beyond their ability to perform. At such a time a period of complete rest in sleep must be taken, and should be continued until the cells are again stored and ready for a period of activity.

When a youth is healthy and his sleep is natural, he will not, as a rule, sleep too long. A good rule is, "Early to bed and late to rise (if necessary), but wide awake and intense all day." Things are accomplished in this world not by long time and weak effort, but by intense application in a short time. Only those who take plenty of sound sleep can have a stock of energy sufficient for sustained effort during even a short time.

A student who spends enough time in sound sleep is never injured by the amount of work expected of him in the schools; but one who spends a night amid the excitements and distractions of a social gathering and takes only a few hours of the morning for a light and fitful sleep, and ends up a series of injuries with a forced and hurried breakfast, can hardly be equipped for a strenuous day's work. The efforts of such an one are attempts to draw from a store which is already exhausted.

How to induce sleep.—Under normal conditions, sleep is perfectly natural and easy, and nature will herself determine the time and the amount that are necessary. But the modern way of living is producing an increasing number of those who suffer from insomnia. The intense activity of the day, accompanied by worry and excitement, the overtaxed mind and body, the stimulation of drugs, the unhygienic forms of dress, the lack of periods of repose and recreation, and indulgence in the use of alcoholic drinks, and the excessive use of tobacco, all tend to produce a condition of the body which is apt to result in insomnia, or at least in very light and restless sleeping. Even without any apparent fault of the sufferer, sleep often comes tardily or not at all.

Narcotics, such as morphine, are often taken to produce artificial sleep, but such a practice is very dangerous, and should be resorted to only on the advice of a competent physician.

Those who have a difficulty in going to sleep may often profit by a few simple rules, as follows:

(1) After being dressed for the night, take some light gymnastic exercises with dumb-bells, and also by rising slowly a number of times upon the toes and then upon the heels.

(2) Take a warm bath and rub the body, thus removing any cutaneous irritation; or simply bathe the feet and legs in cold water.

(3) See that there is sufficient ventilation to keep the air fresh during the night. Sleep on a fairly hard mattress,—never on feathers. Use only light covers.

(4) Do not attempt to think out a problem or make any kind of mental effort after retiring. Get the mind as nearly as possible in a state of inactivity.

(5) Make a serious effort to dismiss all worry and excitement. Keep the mind on some pleasant experience or anticipation. Do not dwell on an imaginary train of possible evils.

(6) Relax every muscle in the body. This is impor-

tant. Even when the body appears to be in repose, it will often be found that several muscles of the legs, arms, or neck are tense. Practise the art of relaxation several times each day, until it can be easily and completely done. Efficiency in the art of complete relaxation is valuable not only for the purpose of inviting sleep, but also for periods of repose which should be taken during the day.

(7) Retire with the intention of at once going to sleep, and thus a habit may be formed in which sleep is associated with that environment.

Good and bad habits.—Habit, as already explained, is a tendency to do again in the same way the things which have often been done before. Habits may be good or bad. Either kind may become fixed. No one cares to get rid of a good habit, and fortunately it would be difficult to do even if one did wish to change it. Bad habits become equally fixed and difficult to change.

It is necessary to any man's success that he should be, in most things, a creature of habit, and, of course, these habits must be good ones. In all things which a man does by force of habit, he will, if his habits are good, do the right thing in the right way without thinking about it. Herein is the great advantage and economy of being a creature of correct habits, and nothing so handicaps a young man or woman as habits which are incorrect.

Bad habits include more than immoral tendencies. A very moral man often has some bad habits. An awkward walk, carelessness in dress, impolite address, improper table manners, wrong forms of speech in common conversation, scrawly and illegible writing, lack of intensity in effort, tendency to slight work, and so on, are all habits which will remain and grow more and more marked, unless they can be forcibly corrected. No education is more valuable to a man or woman than the numerous good habits which may be formed in the earlier years of life, for, in its broadest sense, habit is only another name for character.

In early life the nervous system is in its plastic stage. Habits are then easily formed or changed. But every act, every thought, and every way of doing things make a lasting impression even on the youthful mind. At the age of twenty-five or thirty years the nervous tissue may be said to have become set. Only by a strong effort of the will and by continued practice can a habit hitherto formed be now changed, and it is doubtful that a radical change can ever be made.

The nervous system, however, never *entirely* loses its plastic nature. By persistent effort old habits may be practically changed, though the tendency to return to the old habit is always imminent.

These considerations make the education of the youth of to-day a matter of supreme importance for the sake of the coming generation.

Effect of alcohol on the nervous system.—The nervous system, more than any other part of the body, is injured by the use of alcohol. The same amount of injury to the brain will have a greater evil effect, because the brain is the controlling organ.

An injury to the head of any organization is more serious, as far as the welfare of the organization is concerned, than a similar injury to an inferior member.

We have shown that a centre in the medulla controls the rate of the heart-beat. Any injury to this centre will, of course, affect the action of the heart, though the heart itself may be perfectly sound. In a similar manner whatever affects the vasomotor nerve-centres will modify the circulation of the blood, and any injury to a motor area of the cerebral cortex will affect its control of the muscles which it stimulates to action. The cause of dyspepsia may lie in the nerve-centre which normally stimulates the secretion of the gastric glands.

Thus alcohol works a double evil in that it injures the various organs in ways already explained, and, worst of all, it weakens or finally destroys the nervous centres upon which the other organs must rely for stimulation, nutrition, and recovery from injury.

Mankind has had a long experience with alcohol, and many scientific investigations have been made as to its effects on the human system. Almost without exception its continued use as a drink has been found to have an evil effect. Whether the matter is considered from a physiological, a financial, or a moral stand-point, the use of alcoholic drinks as a beverage is condemned by scientific facts as well as by the experience of mankind. The so-called arguments in its favor are chiefly apologies for its continuance, and the main motive back of the traffic in intoxicating liquors is the source of gain to its promoters.

Alcohol holds an important place in the arts, and it may be useful as a fuel, but it is every day becoming more evident that alcoholic beverages, even in moderate quantities, are evil, and only an evil.

Alcohol in small doses.—There has been, and is now, a prevalent notion that if alcoholic liquors are used in moderate quantity, much good may be derived from them, or at least no injury would be done.

This mistaken notion is the chief cause of both the moderate and the immoderate drinking of alcohol.

The masses of people do not have the facilities or the inclination to investigate the subject; and because they know that a moderate use of malted liquors produces no *apparent* evil, while it does often bring about a feeling of bodily comfort and of mental cheer, they are easily deceived.

The body has within itself wonderful agencies of recuperation. It differs from any other machine in that it can build up and repair itself. Whenever any injurious substance, as alcohol, is taken into the body, an effort is at once made to excrete it; but before this can be done much of it is carried in the current of blood to the various tissues, where it exerts its poisonous effect upon the protoplasm of the cells—particularly the nerve-cells. If the amount of alcohol is small and is much diluted, the injury to the cells may be slight and easily repaired. It should be carefully noted, however, that alcohol, in whatever doses, presents itself to the cells as an enemy, whose evil effects are to be either prevented or repaired.

Because the cells are able to survive the effects of a small dose is no proof that it is not a poison, any more than small doses of arsenic or strychnine might be considered harmless because they do not at once destroy the tissues or arrest the functions of the organs. Food, on the other hand, comes to the cells without any antagonism, and is assimilated in a natural manner.

These facts are of the greatest importance in the consideration of this subject, for the apparent immunity from the evil effects of the small dose is the gateway through which all immoderate drinking steadily creeps in.

This immunity, however, is only apparent. Each recovery from the poisonous effects leaves the nervous system with less ability to resist the next. Its evil effects are thus cumulative, and sooner or later become apparent in a weakened condition of some organ or a suspension of some function.

Most people do not look far into the future or are willing to take chances. Unless serious pain or sickness follows at once upon a certain line of conduct, they are apt to continue in a course which gives present gratification. As a consequence, the evils from moderate drinking are most insidious in character. for irreparable harm may be done before the drinker is aware of his condition.

Alcohol as a mental stimulus.—The first effect of a drink of alcoholic liquor is an apparent stimulation of the nerve-centres to greater activity. This has led many to believe that alcohol has the effect of rousing mental activity, and that one can write and think more brilliantly under such a stimulus. But careful examination will show that alcohol produces in the brain a condition of *excitement* rather than that of healthful stimulation. It may properly be compared to the introduction of a poisonous serpent into the midst of a company of people in an enclosure from which they cannot escape. There would no doubt be intense activity in the company, and great excitement, but the motive in all their efforts would be that of self-preservation.

It would not be probable that this increased activity would result in any worthy accomplishment, and after the serpent is removed it is quite probable that each member of the company would find himself in a state of fatigue, which would prevent any, even natural, effort until after a period of rest.

When one's brain is thrown into a state of excitement by alcohol, he gets an exaggerated idea of his capacity to think and work. He imagines he is doing more than he is in fact. One who writes a production in this state of excitement may at the time be highly pleased with his effort, but a calm review later will show that he greatly overestimated his work.

A hearty meal of good food, abundance of fresh air, and plenty of sleep are the natural and proper provisions for intense and sustained effort.

Immoderate use of alcohol.—Every one abhors the condition of a confirmed drunkard, but nearly every one who drinks immoderately was at one time only a moderate drinker. Immoderate drinking is a natural result of moderate drinking. Under the continuous poisonous effects of alcohol, even in moderate doses, the nervous tissue deteriorates and loses its former delicacy of response to stimuli. More alcohol must now be taken to produce the desired effect. Besides, an appetie for alcohol is gradually contracted, and becomes so strong that all the efforts of the better side of a man's nature cannot resist it. The antidote for alcoholic poison is more alcohol. Considerations of home, family, morals, and respect of others gradually come to count for naught. Such an one is suffering from a self-inflicted disease which is known as *dipsomania*,—madness for drink.

The disease may yield to proper treatment and the patient may again get control of himself, but he never fully recovers, and a very slight temptation will in most cases lead him again into inebriety.

Complete recovery from the effects of immoderate and long-continued use of alcohol is impossible because of the changes made in the character of the nervous tissue. It is found that the brain becomes shrunken in size and the space about it becomes filled with water. Many of the cells degenerate into fat or connective tissue. Thus the essential and vital part of the tissue is sacrificed, and of course the power to think and control the body is proportionately reduced.

The last stage of dipsomania is often *delirium tremens*. This is the most horrible condition to which a human being can be reduced, and may come on at any time during a period of drinking,—even early in the career of the drunkard. It in effect transforms a man into a wild beast. The muscles are all in a tremor, because the poisoned motor centres can no longer control them. The mind is delirious and imagines all sorts of horrible beasts, serpents, and insects, which are ever in pursuit and cannot be driven away. Death may come to the sufferer's relief at any instant, or the torture may last for several days, and then be followed by a return of the rational state.

Hereditary effect.—Nothing in physiology is more clearly established than the fact that children inherit traits, dispositions, bodily and mental strength or weakness from their parents.

Children of drunken parents are often at a great disadvantage because of some inherited weakness. Defects of some kind are usually handed down from a father or grandfather who has been given to the use of alcoholic drinks. Maybe the child will have weak lungs and be predisposed to consumption. Maybe there will be some physical defect in the brain, with a consequent dulness or tendency to insanity. The general tone of both mind and body may be inferior, and the child be thus handicapped for life.

An appetite for strong drink frequently appears in the children of drinking parents. Such an appetite may be aroused by a few drinks of alcohol. Thus, one who persists in drinking alcohol injures not only himself but also all those dependent upon him while he lives, and may transmit the evil effects of his course to generations that follow.

The only safe course.—*There is only one safe course in regard to the use of alcoholic liquors, and that is totally to abstain from their use.* An occasional indulgence in some mild alcoholic drink may do no permanent injury that is apparent; for, as we have explained, the body is able, within certain limits, to repair any organ that is injured. But whatever may be said about the harmlessness of the small dose of alcohol, it is still in accordance with the testimony of the best experts and of the best elements of the human race that the only safe course is total abstinence.

The experience of men in the future will be just as it has been in the past; and the testimony of individuals, communities, and nations in the past is all against the use of alcohol as a beverage.

Tobacco and the nervous system.—Many of the fundamental objections to the use of alcohol can also be urged against the use of tobacco. Tobacco contains a violent poison called nicotine. A very small quantity of this poison in a concentrated form would soon cause death. When by any use of tobacco it is introduced into the current of blood, it of course is carried to the brain as well as to other parts of the body.

Its general effect upon the nerve-cells is much the same as that of alcohol. That is, it tends to do injury, and must be either warded off or the injury must be repaired.

When one has attained his full growth, is healthy, and is engaged actively in some outdoor work, the noticeable physical injury from the moderate use of tobacco may not be easily recognized. To students, clerks, or any whose constitutions are delicate, and whose work is in close rooms, the use of tobacco is very harmful. This is particularly true of the cigarette. Many investigations have been made in regard to the smoking habit among students in college, and every report of such investigation shows that the smoker is inferior in his standing.

The worst effect of tobacco is found in its use by the young. Those who are growing are likely to stunt their growth by the use of tobacco. Nicotine will seriously affect certain nervous centres, thereby causing organic troubles, such as the irregular action and palpitation of the heart so common with those who use tobacco freely or with the youth who uses tobacco at all. Other nerve-centres which regulate secretion and excretion are also injured, so that blood improperly purified is distributed to the various cells. The easily fatigued muscle of the smoker is an evidence of this fact.

Worst of all, the mental powers are weakened. This results both from the poisoning of the brain-cell itself, and also from the fact that the other organs do not furnish pure blood for its nourishment. It will be observed in the public schools that the youth who smokes (if he smokes at all he will usually smoke a great deal) will be restless and inattentive, will lack ability to apply himself and hold his mind to his studies, and of course will fall behind and want to quit school. It is also observed that students who are in college and who are habitual smokers cannot with credit meet the requirement in those studies which can be mastered only by concentrated effort and attention. This statement can be verified by college statistics on this point.

Cigarette smoking is the most injurious use of tobacco for the reasons already given under the subject of respiration.

Opium.—Opium is a powerful narcotic poison. Its use is not so common in the United States as is that of alcohol and tobacco, but it is all too common. The victims of the opium habit yield to an appetite which they are helpless to resist. and sink to extreme degradation of both mind and body. The druggists of almost every town can point out a number of both men and women who will resort to any deception to secure opium. They will lie or steal, if necessary, to secure the money to buy the drug. The victims are stealthy in their practice, and will usually deny that they use it, so that the prevalence of the habit is not commonly known.

The opium habit is easily contracted. Morphine is a tincture of opium and is frequently used to allay pain. Its continued use may engender in the system a craving for it which is difficult to resist.

Some patent medicines, which are advertised as "pain-killers" and "stomach bitters," contain as much as 40 per cent. or more of alcohol and often a considerable quantity of morphine. Both drugs are narcotics, and of course will stop pain by paralyzing the sensory nerves.

In such ways the unsuspecting victim may after a time find himself a slave to the opium habit, from which it is very probable he will never be free.

QUESTIONS FOR REVIEW.

1. Why is blood distributed to the nervous system?
2. What connection is there between food and nervous operations?
3. Show how the brain is the favored organ of the body. Why is this so?
4. How can we supply the brain with healthful food?
5. How is blood conducted to the brain?
6. Explain why brain-cells become fatigued.
7. How does a fatigued cell differ from a rested one?
8. What is the condition of the body and mind during sleep?
9. What is the purpose of sleep?
10. How much sleep is necessary?
11. Will study injure the mind? What will?
12. What is insomnia? What causes it?
13. Give some good ways of inducing sleep.
14. What is meant by repose and relaxation?
15. In a broad sense, what is meant by good and bad habits?
16. What is the best time of life for the formation of habits? Why?
17. Why is an injury to the brain more serious than an injury to other organs?
18. How does injury to the brain work a double evil?
19. Tell all you can about the use of alcohol in small doses.
20. Is alcohol beneficial as a stimulus to mental activity? Explain.
21. What is the best condition of the brain for clear and strong thinking?
22. Describe dipsomania.
23. What is the hereditary effect of excessive drinking?

24. What is the only safe course in reference to the use of alcohol?

25. Describe the effects of tobacco on the nervous system.

26. Tell all you can about the opium habit.

27. What is opium, and where is it produced? (See dictionary and cyclopædia.)

CHAPTER XVIII

THE SPECIAL SENSES

What the special senses are.—The special senses are those which are produced by special organs at the outer ends of sensory nerves. They are *seeing, hearing, touching, tasting,* and *smelling.* The special organs which produce these sensations are the *eyes,* the *ears,* the *touch corpuscles,* and the special endings of the *gustatory* and *olfactory* nerves.

General sensations.—There are many other sensations in the body which may, more properly, be classed as general sensations. These are such as

(1) The *sense of temperature,* which is located principally in the skin. By this sense we are promptly informed as to whether the temperature is too high or too low for the most successful operation of the cells and organs which are affected. This sense is also acute in the mouth and at the entrance of the nose. These are the points of entrance of food and air, and, as we might expect, we find here several outposts, or guards, such as touch, taste, smell, and this additional one,—the sense of temperature.

(2) *The sense of pain.* When any sensory nerve is injured or is excited beyond what is natural, a sense of pain results. When the epidermis is removed from any part, as in case of a blister on the finger, contact with

the exposed true skin will produce pain rather than a sense of touch. While pain is sometimes considered a great evil, yet it is in fact a very great blessing, for otherwise we would become very careless in regard to the health of our bodies. Even if we always tried to do what was best, we would often be ignorant of the effects of our course except as we were checked by pain. The cause of pain, and not the pain itself, is the thing to be avoided.

(3) *Sense of hunger, thirst, fatigue, or illness* are all general senses which are very vague in their character. They cannot be definitely located, and are probably the combined result of sensory impulses from all or many cells of the body. Their purpose is to inform the cerebrum as to the state of the cells in reference to their ability to perform their natural functions.

(4) *The sense of weight.* By this sense it is possible to determine the weight or resistance of an object by the amount of muscular exertion. This sense may be so trained that it becomes fairly reliable.

(5) *The sense of pressure.* This sense is most delicate on the forehead, where a slight increase or decrease of pressure may be detected.

Advantage of the special senses.—By means of the special senses we are able to gain *clearly defined knowledge* of objects outside the body. If the fine branches of the optic nerve were distributed in the skin of the face, we could probably tell darkness from daylight, but could never have distinct images of objects such as we get when light first passes through the eye and then falls upon the nerve-ends. Similarly, we might get an idea of some intense sounds without ears, but the sensation would lack all distinctness and delicacy.

The five special senses are the five great avenues through which all, or nearly all, our knowledge is gained. It is through them that connection is made between the outside world and the central nervous system. If all sensations were suddenly to cease, a man would continue to live, but it would be impossible for him to determine whether he existed or not. He would for a time continue to think as a result of his store of previous sensations, but soon these would fade away, and his mind would become a complete blank. Thus we are in constant dependence upon the streams of sensation from our special sense organs.

The two great media.—Every minute of our lives we must be surrounded by two great media,—the *air* and the *ether*. We might expect, then, to find, as we do find, that two of the most valuable and delicate sense organs are the ones which record any disturbance in these media,—the ear being a receiver for waves of air, and the eyes for waves of ether.

The ether fills all space and permeates all matter. When it is agitated at any point, waves pass out in every direction, like the waves which go out from the point where a stone is thrown into a still pond, only the ether waves will go out in all directions as radiations from the centre of a sphere. The sun is constantly sending out waves of this kind, and they travel the whole distance—about 93,000,000 miles—from the sun to the earth in eight minutes. Thus the earth is flooded with waves which cause nearly all the light and heat we have on earth. In the same manner light comes to us from the stars, which are vastly farther away than the sun. Thus the eye, more than any other sense, gives us knowledge of objects at a great distance from the body. The region from which we could gain knowledge would be very limited without this sense.

The air also constantly presses about us, and any vibrating body will start in it a series of waves that will travel out in all directions. These waves, however, consist of alternate condensations and rarefactions of air, while the ether waves are simple undulations. The air waves travel only about 1100 feet in one second and cannot go very far, but probably fully as much information is brought to us on air waves as on the ether waves.

Thus the eye and the ear are our two great sense organs, because they are made to receive the vibrations which are constantly brought to us on these two great and ever-present media.

THE EYE

General anatomy of the eye.—The eye is nearly spherical in shape, is nearly one inch in diameter, and is set in a bony socket upon a bed of fat. Its principal parts may be seen in the cross-section shown in Fig. 126. On the outside is the *sclerotic coat*, which on the front of the eye is transparent and bulges forward, forming the *cornea*. Just back of the cornea is a cavity filled with a watery fluid called the *aqueous humor*. Across the rear part of this chamber is stretched a curtain called the *iris*, through the centre of which is a round opening called the *pupil*. Just back of the iris is the *crystalline lens*, resting in a concave depression of the *vitreous humor*, which fills the large central chamber of the eyeball. Next within the sclerotic coat is the dark-brown *choroid coat*, which is continuous in front with the iris. The inner coat is the *retina*. The *optic nerve* enters the eye a little below and to the inner side of the ball, and its numerous branches are distributed to the retina. On the retina, in the centre of the back part of the ball, is a spot about one twenty-fourth of an inch in diameter. It is yellow in color, and so is called the *yellow spot*. This spot is in line with the axis through the cornea and the crystalline lens.

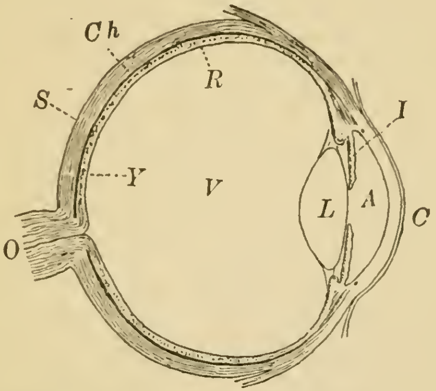

FIG. 126.—Cross-section of the eye. *C*, the cornea; *A*, aqueous humor; *I*, iris; *L*, crystalline lens; *V*, vitreous humor; *S*, sclerotic coat; *Ch*, choroid coat; *R*, retina; *O*, optic nerve; *Y*, yellow spot.

The purpose and operation of the anterior parts.—The function of the cornea, iris, and crystalline lens, all working together, is to produce a small but distinct image and locate it exactly on the yellow spot of the retina. The cornea is fixed in position, but the iris will change the size of the pupil in accordance with the brightness of the light, and the lens will change its shape in accordance with the distance of the object. The cornea produces the image, the iris regulates the amount of light, and the lens locates the image upon the yellow spot.

The cornea.—The cornea is the transparent part of the sclerotic coat. It is much more convex than the remaining surface of the eyeball, and is set into the remaining portion of the sclerotic coat much as a crystal is set into the case of a watch. The distance across the cornea is about one-sixth the circumference of the ball. In the normal eye the cornea has the shape of a segment of a sphere, its curvature being the same in all directions. The curvature is greatest in youth and becomes less and less as age advances.

The function of the cornea is to receive the rays of light which come to it from a point outside the eye, and bend them so that they will meet again at a point within the eye. This is done in accordance with a principle in light called refraction.

Refraction of light.—Whenever a ray of light passes obliquely from one medium to another of different density it will be bent out of its course. This is called *refraction* of light. In Fig. 127, A, a ray of light from *O* enters obliquely into a piece of glass. That is, it goes from a light medium, the air, into a dense medium, the glass. In that case the ray is always bent towards the

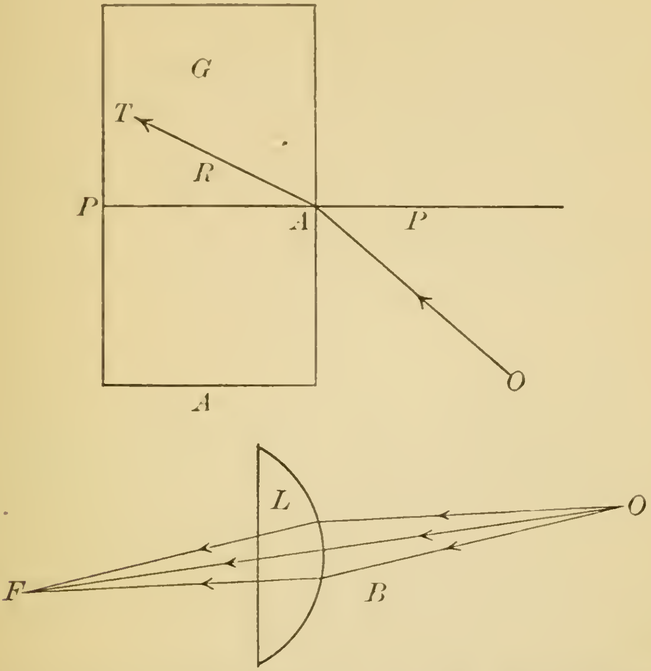

Fig. 127.—In *A*, a ray starts from *O*, in air, and enters plate of glass, *G*. *R* is the direction of refracted ray.

In *B*, the rays from *O* are refracted by lens *L* and brought to point *F*.

perpendicular, *P P*. In case the light would start in the glass, as at *T*, then the ray, *T A*, on going out into a lighter medium, the air, would be bent away from the perpendicular, *P P*, and would go to *O*.

Now, if we take a lens in the shape of the cornea, as in 127, *B*, and apply these laws of refraction, it will be plain that the rays of light from *O* will be bent so that they will come together at *F*.

Thus, as shown in Fig. 128, if an arrow, *O*, be the object, then rays of light from any point of the arrow will,

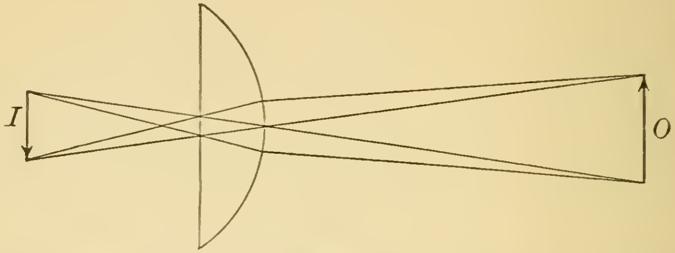

Fig. 128.—Rays of light from each end of the arrow, *O*, are brought to a focus at *I*.

after passing through the cornea, be bent so that they will come together again, and form an image of that point. In the figure only two rays are drawn from each end of the arrow, as that is all that is needed to find the two ends of the image. The image of other points of the arrow will lie between the two ends. It is observed that the image is inverted, and that is the position of all images in the eye. The cornea alone will produce a distinct image, but it cannot produce satisfactory vision without the aid of the iris and crystalline lens, as will now be explained.

The iris.—Iris in mythology was the goddess of the rainbow, and hence the name of this curtain with its variety of color. The iris is the chief source of the beauty of the eye, but nature intended it for a useful purpose in vision. In the iris are two sets of muscle-fibres. One kind radiates from the pupil to the outer edge of the iris. When these contract they pull the iris away from the centre in all directions, thus making the pupil larger. In the other set the fibres are concentric about the pupil, and when they contract the iris is drawn towards the centre, and thus the pupil is made smaller. The action is automatic, a bright light causing a contraction of the concentric fibres and so a smaller pupil, and a dull light permitting the iris to be drawn back and so a larger pupil.

The purpose of this arrangement is twofold: (1) To produce on the retina an image of the same brilliancy, whatever be the intensity of the source of light. Vision would be dimmed by too much as well as by too little light, and too bright an image would injure the retina. (2) To shut out the rays which would otherwise pass in through the edges of the cornea and crystalline lens and

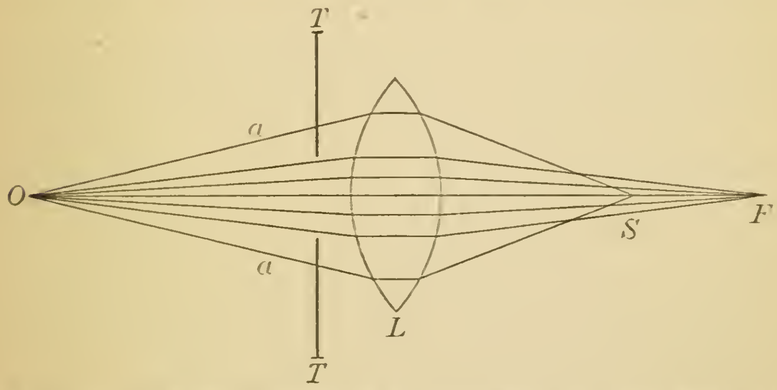

FIG. 120.—Diagram illustrating the aberration of focus caused by a spherical lens. *O*, origin of light; *F*, focus where the five rays through the central part of the lens meet; *a*, *a*, the rays which pass through outer edge of lens and are focused at *S*; *T*, *T*, is a screen corresponding to the iris in the eye. It shuts off all rays except those which pass most nearly through the centre of the lens.

would not come to a focus at the same point as the other rays, which entered near the centre of the cornea. This is illustrated in Fig. 129. The value of the iris in this respect is experienced by those who have belladonna placed in the eye to cause the pupil to expand so that the interior of the eye can be examined. Clear vision is impossible until the effect of the belladonna has passed away.

In many optical instruments a screen with a round hole through the centre is placed in front of the lens to secure a distinct image according to the principles just explained.

The crystalline lens.—The *crystalline lens* is a transparent colorless body in the shape of a double convex lens. It is about one-third of an inch broad and one-sixth of an inch through its thickest part. On its anterior side it is bathed with the aqueous humor and is in contact with the iris. On its posterior side it rests in a concave depression of the vitreous humor.

The convexity of the lens is greater on the posterior side. In old age the lens becomes flatter and less transparent. In structure the lens is made up of a number of concentric layers, or lamina, much like the structure of a lily-bulb or onion.

The lens is held in place by a ligament, which is attached all around its edge. This ligament is attached also to a ring of muscle-fibres at the front edge of the choroid coat. This muscle, known as the *ciliary muscle*, is composed of both circular and radial fibres. An idea of the relation of these parts may be obtained from the diagram in Fig. 130.

The lens is elastic, and when left to itself its sides will bulge out and become quite convex, but the suspensory ligament is constantly under tension, thus flattening the sides of the lens. When, however, it becomes necessary for the lens to be more convex, the ciliary muscle contracts and thus relieves the tension of the ligament.

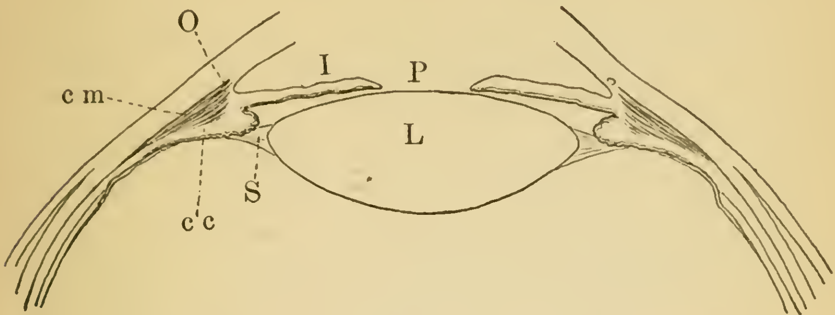

FIG. 130.—Section showing attachments of the lens. *cm*, ciliary muscle; *cc*, front edge of choroid arranged in folds called the ciliary processes; *S*, suspensory ligament; *P*, pupil; *I*, iris; *O*, origin of ciliary muscle.

The chief function of the lens is to regulate the amount of refraction so that the rays of light will meet and form an image on the yellow spot of the retina.

How we can see distinctly at various distances.—As long as the distance between any object and a fixed lens remains the same, the distance of the image on the other side of the lens will remain the same. If the distance of the object is changed, the position of the image will be shifted. This is illustrated in Fig. 131. When *O* is moved towards the lens, *F* moves farther away, and when *O* is moved away, *F* approaches the lens. Thus, if the crystalline lens of the eye were fixed in position and shape, we would be able to see distinctly only at a definite distance. If the distance for any eye happened to be ten feet, say, then only the objects at that distance could be seen distinctly. This would evidently be very inconvenient, and so nature has provided a method of adjustment which is very simple and is operated without any attention on our part.

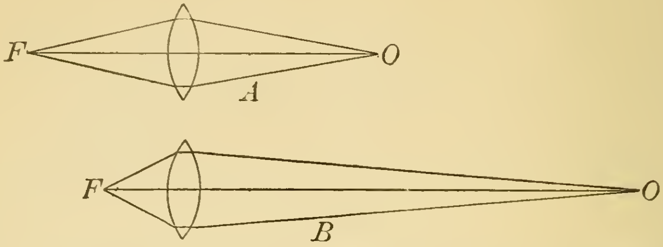

FIG. 131.—Diagram showing how the focal distance, *F*, depends on the distance of the object, *O*, in the same lens.

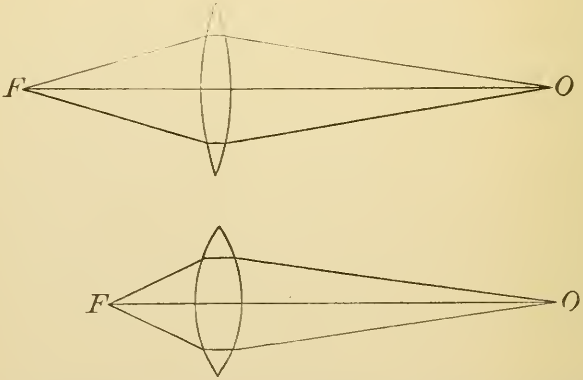

FIG. 132.—Diagram showing the effect of lenses of different curvature. *O* and *O* are objects at the same distance from lens. The lens which is more convex brings the rays together at a shorter distance from the lens.

The more convex any lens is, the more it will refract a ray of light. This is illustrated in Fig. 132. This is the principle utilized in the eye, and the convexity of the crystalline lens is changed in the manner already explained, for different distances. Thus, if the upper lens, Fig. 132, is just the right convexity to throw *F* upon the retina, then the convexity of the lower lens is too great, and *F* there falls short of the retina. In that case the ciliary muscles relax and the tension of the suspensory ligament is restored. This makes the lens flatter, and thus the image is moved to the proper distance.

The emmetropic eye.—In a normal eye parallel rays of light will be focused on the retina without any action of the ciliary muscle. For near objects the rays that enter the eye will be divergent, and then the lens will become more convex and will bring the rays together at the same point. Such an eye is *emmetropic*, and is capable of adjustment for any distance to within about eight inches from the eye.

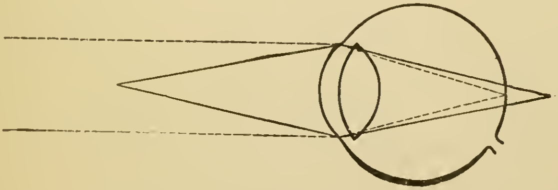

Fig. 133.—Emmetropic eye.

The myopic eye.—When parallel rays come to a focus before the retina is reached, the eye is said to be *myopic* (Fig. 134). This condition may result from too great a curvature of the cornea or the lens, or it may be due to an elongation of the ball of the eye. By reference to Fig. 131 it is plain that if an object be held near the eye, a certain distance may be found where the image will fall exactly on the retina. For distinct vision an object must always be held close to such an eye. The defect is called *short-sightedness.* It can be corrected by the use of concave glasses. A concave lens always tends to scatter the waves of light, while convex lenses always tend to bring the rays to a focus. Hence concave glasses may be ground so that they will just correct the defect in the convex lenses of the eye, and the image will be thrown upon the retina as in the normal eye.

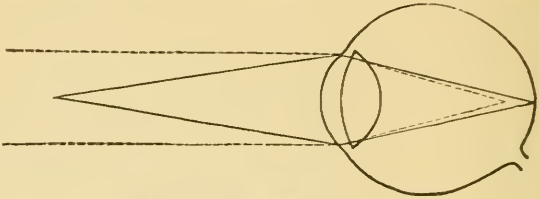

FIG. 134.—Myopic eye.

The hypermetropic eye.—It often occurs that even when the lens is as convex as the eye can make it, still the image falls beyond the retina (Fig. 135, *c*). This may result from the fact that the cornea is not sufficiently convex, or the distance from the lens to the retina may be less than in the normal eye. This defect may be so slight that only very near objects are indistinctly seen, or it may be so great that even the parallel rays from objects at an infinite distance may be focused beyond the retina. Since greater refraction of the rays is needed, it is plain that convex glasses will correct the defect.

Such an eye is said to be *far-sighted*. Nearly every one who has passed the age of about forty-five years is, to some degree, far-sighted. The cause is that the cornea becomes less convex and the lens less capable of adjustment as age advances. This is why middle-aged and old people wear glasses when they read or look at minute objects near by.

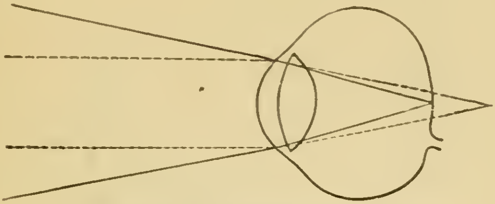

FIG. 135.—Hypermetropic eye.

Movements of the eyes.—For distinct vision it is necessary that the image fall upon the most sensitive part of the retina, which is the yellow spot. This spot is in line with a ray of light that would pass through the centre of the cornea, the pupil, and the lens.

One can see indistinctly all four walls of a room by taking a position near one corner, because the retina lines the interior of the eyeball almost to the iris. But when we wish to see anything distinctly, we must look straight at it. To do this we turn the head or move the eyes in their sockets.

Six muscles are attached to the sclerotic coat of each eye. Four of these are called the *recti*, or *straight*, muscles. One is attached above, one below, and one on each side.

When the upper one contracts, the front of the eye will be turned upward, and each of the other three will in the same way turn the front of the eye to the side to which the muscle is attached. The *superior* oblique muscle is peculiar in that its tendon passes through a cartilaginous ring (Fig. 136, 6), and, passing on, is attached to the side of the eyeball. The ring thus acts as a fixed pulley, and a contraction of this muscle would tend to roll the ball in its socket. The *inferior oblique* muscle also tends to rotate the ball, but in a direction opposite to that produced by the superior oblique.

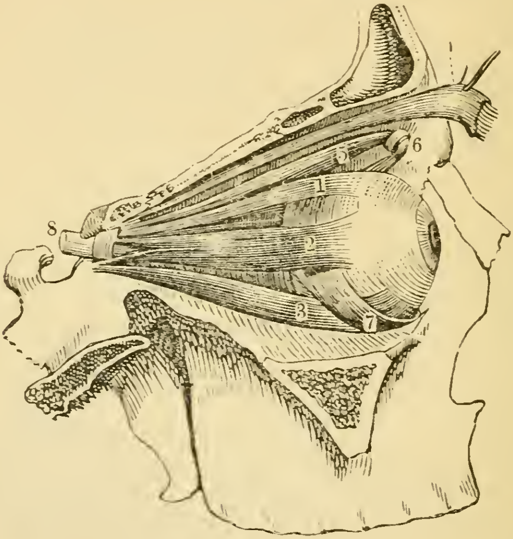

Fig. 136.—Muscles of the eye. 1, 2, 3, 4, recti muscles; 4 is opposite 2 and cannot be seen in cut; 5, superior oblique muscle; 6, pulley through which the tendon plays; 7, inferior oblique muscle; 8, optic nerve.

These two muscles, then, are antagonistic to each other and hold the ball steadily in place.

Effect of defective eye-muscles.—It is evident that if any one of the muscles attached to the eyeball should be paralyzed, or should be too short or too long, the ball would not have a correct position in its socket. If the outside recti muscles are too short or the inside ones should be paralyzed, the eyes would turn outward. If, as often happens, the inside rectus pulls harder on the ball than the outside one does, the eye will be turned inward, and cause *squinting* or *cross-eyes.*

Any lack of balance between the eye-muscles will result in defective vision, and will also be objectionable from the stand-point of personal appearance. Fortunately, a skilful surgical operation will usually correct such defects.

The posterior parts of the eye.—Thus far we have been chiefly concerned with the descriptions and functions of those parts of the eye which had to do with the formation and location of the image. These, we have seen, are, for the most part, in the anterior regions of the eye. It remains to be seen how the image is received by the terminations of the optic nerve, and how the stimulus is conducted to the seat of perception in the brain. This is effected through agencies in the posterior part of the eye.

The retina.—The sclerotic coat is on the outside of the eyeball. It is composed of tough, white fibrous material, and is usually called the "white of the eye."

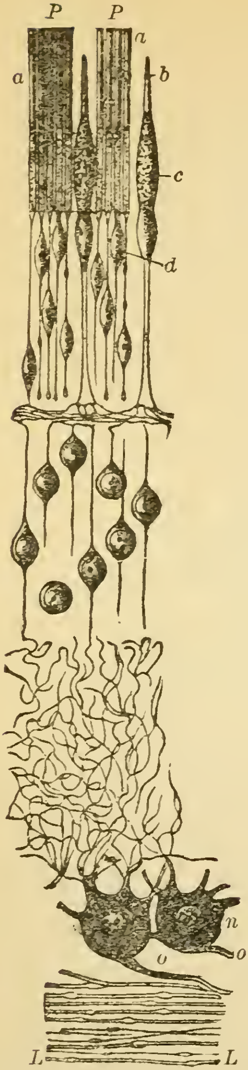

FIG. 137.—Diagram showing the nerve elements of retina; *aa*, rods; *b*, cone; *c*, nucleus of cone; *d*, nucleus of rod; *n*, nerve-cell; *oo*, fibres of optic nerve; *LL*, internal limiting membrane; *PP*, pigment-cell layer.

The next coat is the choroid, which is of a dark color, and is very vascular, being filled with a net-work of blood-vessels.

The innermost coat is the retina, which will now be more fully described.

The retina lines the whole posterior cavity of the eyeball and extends forward nearly to the iris. It is only about one-fiftieth of an inch thick at the point directly opposite the iris, where it is thickest. It is composed chiefly of terminals of the nerve-fibres of the optic nerves, with certain sustaining tissue that holds the nerve elements in place.

The anatomist distinguishes ten different layers of the retina, the most important of which are pointed out in Fig. 137. The whole distance from *P P* to *L L* in the figure represents the thickness of the retina, so that the parts here shown on a large scale can be seen only by aid of a strong microscope. The line *L L* represents the limiting membrane which lies next to the vitreous humor, while the line *P P* represents the pigment-cell layer which lies adjacent to the choroid coat. These are respectively the first and tenth layers of the retina. The other eight layers are between, and have a variety of structure, being composed mainly of nerve-cells, nuclei, nerve-fibres, and special nerve terminals.

The ninth layer is composed of nerve-cells of special forms called *rods* and *cones*. In Fig. 138 is shown one of each of these two kinds of cells, very highly magnified. Their name—"rod" and "cone"—is plainly suggested by their shape. Three or four rods are, as a rule, found between every two cones. The light passes nearly through the retina before it reaches these cells.

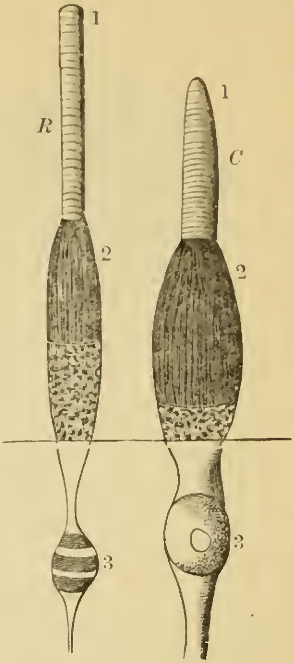

FIG. 138.—Rod and cone from the retina. *R*, rod; *C*, cone; 1, process; 2, body; 3, nucleus.

The yellow spot and the blind spot.—Two spots appear on the posterior wall of the retina. One is a white circular spot, which is slightly elevated, forming the *optic papilla*. This is the point of entrance of the optic nerve, and is called the *blind spot*, because it contains no nerve terminals, and hence an image falling upon it produces no sensation. Near by is another spot which is circular or oval in shape and yellow in color. It is called the *yellow spot.* Its diameter is only about one-twenty-fourth of an inch. Here the layer of nerve-cells is thicker than elsewhere, and in the ninth layer only cones are found.

In the centre of the yellow spot is a conical depression, where all the layers of the retina are removed down to the cones, and the dark pigment layer shows through, making the depression look like a hole through the retina. This spot is called the *central fovea.* It is a condition for the most distinct vision that the image fall upon the central fovea.

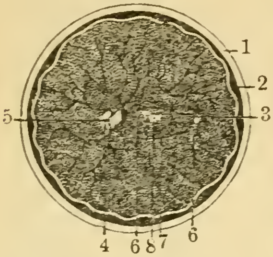

FIG. 139.—Retina seen on its posterior inner surface. 1, sclerotica; 2, choroidea; 3, retina; 4, the optic papilla; 5, central retinal artery; 6, a slight fold of the retina; 7, the yellow spot; 8, its central fovea.

The blind spot is about one-tenth of an inch from the yellow spot, towards the inner side of the eye.

The size of the image.—The image on the retina may cover a large portion of the posterior part of the retina, but only a very small portion of it can be distinctly seen. The whole page of this book is imaged on the retina while you read, but not more than a single letter can be seen distinctly at one time. Reading is accomplished by moving the eyes so that the image of each letter is rapidly swept across the yellow spot.

The smallest object which can be seen as having any dimension must form an image at least large enough to reach from one cone to the next adjacent one in the central fovea of the yellow spot.

Experiment shows that when two points are so close together that lines drawn from each to the eye make with each other an angle of fifty seconds, then the image of these two points on the retina would be only $\frac{1}{6000}$ inch apart. The distance between two adjacent cones is also $\frac{1}{6000}$ of an inch. Fifty seconds then is the limiting visual angle for seeing two points as separate. Any less angle would cause the two points to appear as one. This is the case with many double stars which, to the naked eye, appear as one, but in the telescope are seen to be double.

What seeing is.—Waves of light from an object are refracted so as to form an image on the rod and cone cells of the retina. These waves act as a stimulus and set up nervous impulses which travel along the fibres of the optic nerve to the base of the brain, and thence by other neurons to the seat of visual sensation in the occipital lobe of the cerebrum. The seeing is in the brain and not in the eye. If the optic nerves were severed, the eye could still form perfect images on the retina, but there would be no vision.

The optic nerves.—The optic nerves arise from the base of the brain at what is called the *optic chiasma*. The nerve-fibres which compose the optic nerves have their termination in the seat of sensation in the brain, but on their way from the eyes they meet in the optic chiasma, where most of the fibres pass across to the other side, as shown in Fig. 140.

Part of the fibres, however, pass on to the brain on the same side. Thus each eye sends impulses to both hemispheres of the brain; and even if one side of the brain should be paralyzed, there would still be vision from both eyes.

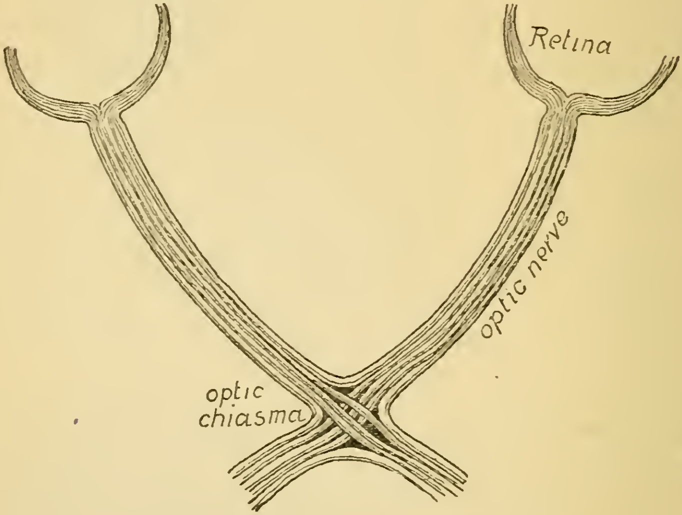

FIG. 140.—The optic nerves.

Advantage of two eyes.—When both eyes are used an image is formed on corresponding parts of the retina in each eye. Similar impulses are thus sent to each hemisphere of the cerebrum and, as the sensations agree, an object is seen singly. By a slight pressure of the finger against the side of one eyeball, the inage on the retina may be shifted so that its position does not agree with that in the other eye. An object then appears distorted or double.

By the use of two eyes all objects can be seen with greater distinctness, and solid objects are made to stand out as solids.

Color sensations.—The eye is so constructed that different nervous impulses are produced by the different wave-lengths of light. This gives us the ability to distinguish colors, for difference in color results only from difference in the wave-length of light.

These waves have been measured, and it is found that when 395,000,000,000,000 of them flow into the eye in one second, the sensation will be what we call red. When the number is 760,000,000,000,000 per second, the sensation is called violet. The waves are longest for red and shortest for violet, while various other wave-lengths produce all the intervening colors.

Some able scientists believe that the nerve-terminals in the eye are of three distinct kinds. One kind, when stimulated alone, will give rise to the sensation of red; another kind, green; and a third kind, violet. When all three are stimulated equally, the combined sensation is white. Gray is a low degree of whiteness. All other colors are mixtures of certain proportions of these three primary color sensations.

The eyes of some persons are deficient in ability to distinguish certain colors. Such persons are said to be *color-blind*.

The inability to distinguish red and green is the common defect.

About four men out of every hundred and one woman out of every two hundred are said to be color-blind.

Nature's provision for the protection of the eyes.—Since the eye is such a delicate and useful organ, it must be well protected from possible harm, for an injury to it is, indirectly, an injury to the whole organized body.

The safeguards placed about the eye are (1) its position in a bony socket, (2) the eyelids and eyebrows, (3) the tears and oil secretions, and (4) the sensitive conjunctiva.

Any flat object, as a book or the open hand, pressed over the region of the eye, will be arrested before it touches the eyeball. Thus the eye is protected by its deep position in a bony socket.

The eyebrows keep sweat or other liquid from running down into the eyes.

The eyelids and lashes are a constant protection against dust and insects, and by frequently closing and opening, the lids wash the surface of the eye and keep it uniformly moist.

The tears are very necessary for keeping the exposed part of the eye clear and transparent. Beneath the skin near the outer end of the eyebrows is a racemose gland which secretes a liquid called tears, and pours it through a dozen or more ducts onto the surface of the eye. The ducts open beneath the upper eyelid, near the outer corner of the eye. At the inner corner of the eye is a provision for carrying any excess of tears into the nostrils. This can be understood from an examination of Fig. 141.

At the inner angle of the eye, on each eyelid, may be seen a slight elevation. These are the *lachrymal papillæ.* On the summit of these is a small opening called the *lachrymal punctum.* Tears enter these openings, and are carried back through the canal to the *lachrymal* sac, and escape thence into the nose.

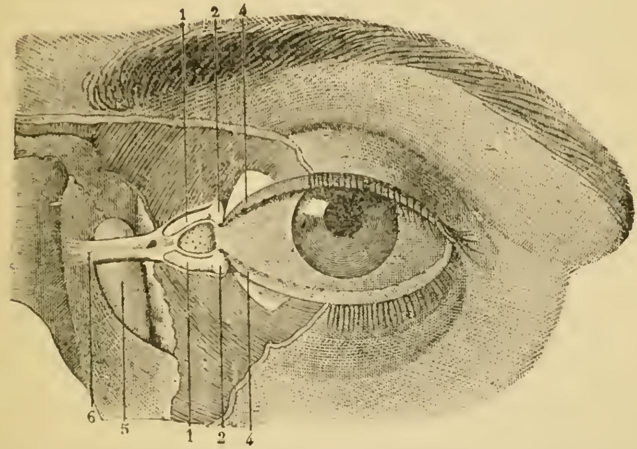

FIG. 141.—The left eye, with a portion of the eyelids removed, to exhibit the lachrymal canals and sac. 1, lachrymal canals; 2, commencement of these on the lachrymal papillæ; 4, edges of the eyelids; 5, lachrymal sac; 6, internal palpebral ligament.

In the eyelids are also a number of small glands which secrete an oily substance and pour it out on the edges of the lids.

The tears keep the cornea always clean and moist, and the oil keeps the tears from flowing over at the edge of the lids.

The inner surface of both lids and the whole visible front of the eyeball are covered by a delicate and very sensitive mucous membrane called the *conjunctiva*. The sensitiveness of this lining quickly calls attention to the presence of any foreign substance in the eye.

Care of the eyes.—Although every one places a high estimate upon the value of his eyes, yet no other organ is more frequently misused. The eye has wonderful powers of recovery from the effects of mistreatment, but sooner or later some weakness of the eyes will appear if they are persistently abused.

The reading of fine print is injurious. Reading by sunlight or a very strong artificial light will injure the retina. Reading by twilight or a weak and flickering artificial light will strain the eyes. It is injurious to read on a railroad train, because the jolting requires a constant readjustment of the lens.

The habit of reading while lying on a lounge or after going to bed, works a serious injury to the eyes, and has been the direct cause of blindness. Holding a book too close to the eyes will strain the adjusting mechanism and cause short-sightedness. One should not bend over and look down upon the work in which he is engaged. A book should be held in front about fourteen inches away for a normal eye.

The light should be admitted at the rear and left side of the room where pupils study and write or do any work requiring a constant use of the eyes. Artificial light should always fall over the left shoulder upon the page of a book.

If the eyes smart, pain, or have a full feeling, they need rest, and should be examined by an oculist for any defect which might be corrected by glasses. Permit only a perfectly reliable and competent physician or oculist to prescribe for the eyes.

Maintain a healthy tone of the whole system and the eyes will be stronger to meet the demands which are constantly made upon them.

Alcohol seriously affects the eyes by its injurious effects upon the whole body, thus decreasing or poisoning the source of nourishment to the eyes, and also directly by its paralyzing effect upon the optic nerve and by the inflammation which results from the congested blood-vessels. Blood-shot eyes are marks of the alcohol drinker.

The use of tobacco also, particularly the smoking of cigarettes, frequently works serious injury to the organs of vision. This is particularly true of those who are pupils in school and those whose work is indoors. Doctors often refuse to treat the eyes unless the patient will cease from smoking, at least during the time of treatment.

THE EAR

The second great medium in which we always must live is the air. It is natural that we should have an organ which is capable of receiving any disturbance in the air and applying it as a stimulus to the ends of a nerve so as to produce a sensation in the brain. Such an organ is the ear, and the sensation produced is called *sound.*

The nature of air-waves.—Light-waves have been explained as a series of undulations which might be compared to the undulating waves which are seen on water. But waves of air that produce sound are very different from light-waves.

If air could be seen while it is carrying sound-waves it would be noticed that at one point the particles would be crowded together; a little farther on they would be more widely separated, and still farther they would be crowded again, and so on. The crowded condition of the air is called a condensation, and between the condensations are the rarefactions. This condition is represented in Fig. 142, where a vibrating body at O is sending out condensations and rarefactions in all directions. Only a small section of the waves is shown in the figure.

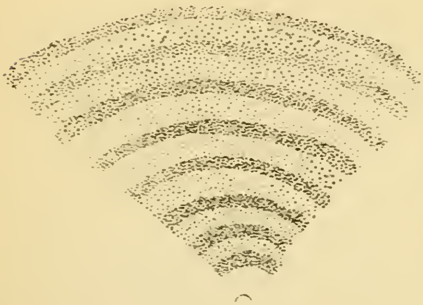

FIG. 142.—Condensations and rarefactions in air-waves.

When the air is very much condensed and rarefied the sound is intense or loud. This is the condition of the air close to a vibrating body, but the amount of condensation grows less and less as the distance increases, and thus sounds are faint when the vibrating body is far away.

Each wave of sound is composed of one condensation and one rarefaction. When the waves are very close together, so that a great number of them reach the ear in one second, a note having a high pitch is produced. These waves travel through the air at the rate of about 1100 feet in one second. They move faster when the air is warm and slower when it is cold. When the number of waves per second is about sixteen, they begin to produce a sensation of a very low sound. As the number of waves increases, the pitch rises, until, when the number becomes about 40,000 in a second, the ear is no longer affected by them.

The ear.—It is difficult to decide between the eye and the ear as to which is of greater service to man. It appears that those who are blind are capable of a better sort of mental culture through their ears than those who are deaf and are compelled to gain their knowledge chiefly through their eyes.

The ear is a very delicate and complex organ, and some of its parts are exceedingly difficult to explain. The subject may be discussed under three heads,—the *external ear*, the *middle ear*, and the *internal ear*. The first two are concerned only in receiving and transforming the sound-waves so that they may properly excite the terminals of the auditory nerve. These, then, are similar in function to the parts in the front of the eye which formed and located the image on the terminals of the optic nerve.

The external ear.—The *external ear* is composed of the *pinna* and *meatus*. The pinna is the part of the ear that projects from the side of the head. It is composed of elastic cartilage covered with skin. As may be seen in Fig. 143, the outer rim is called the *helix*. The soft, pendent part at the lower end is the *lobe*. The deep depression near the centre is the *concha*, which is partly divided by the commencement of the helix. At the bottom of the concha is the entrance to the *meatus*. The pinna collects the waves from a larger area of air and directs them to the mouth of the meatus. Thus the sound is made more intense, just as a high tide may be caused at the narrow head of a bay by the feeble waves collected from a large area at the mouth of the bay.

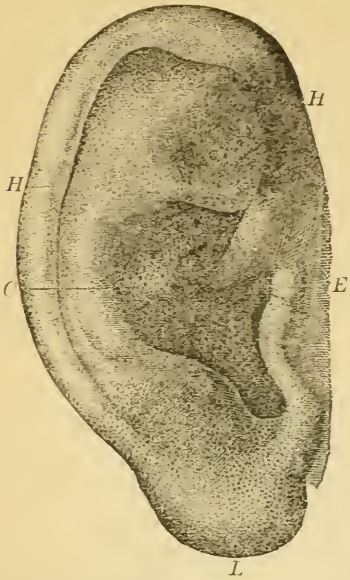

FIG. 143.—Pinna of ear. *H*, helix; *C*, concha; *L*, lobe; *E*, entrance to auditory meatus.

In many animals the pinna can be freely moved by the action of muscles which are attached to it. Muscles are also provided for this purpose in man, but so seldom have they been used that in most people they have lost their power.

The second part of the external ear is the *auditory meatus*, or *canal*, which is about one inch long, and extends from the concha to the drum-head of the middle ear. The first part of the canal, about one-half inch in length, is formed of cartilage, and the remaining part is through bone. The whole is lined with a very thin skin, which also covers the outer side of the drum-head. Beneath the skin in the cartilaginous portion are numerous glands which secrete the ear wax. This wax is bitter and sticky, and, with the aid of hairs at the entrance of the canal, keeps insects and dust from reaching the drum-head.

The middle ear.—The *middle ear* is a cavity in the temporal bone between the external and internal ears. It is called the *tympanum*, or *ear-drum*, because it contains air, and a membrane is stretched between it and the meatus. Upon this membrane the air-waves beat as upon the head of a drum. The drum communicates with

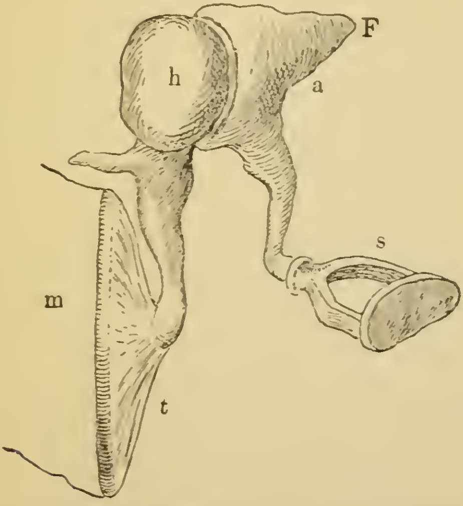

FIG. 144.—The tympanic membrane and the ossicles of the middle ear. *m*, meatus; *t*, tympanum; *h*, malleus, or hammer; *a*, incus, or anvil; *s*, stapes, or stirrup.

the outside air through the *Eustachian* tube, which connects it with the pharynx.

Within the drum is a chain of bones which are articulated to each other, one end of the chain being fastened to the drum-head and the other to the oval window of the inner ear. The bones are called the *ossicles* of the middle ear. Their relation to each other and to the tympanum may be seen in Fig. 144.

The shape of the bones has suggested the names *hammer*, *anvil*, and *stirrup*. The corresponding Latin names commonly used are *malleus*, *incus*, and *stapes*.

The purpose of the middle ear is to receive the feeble waves which beat upon the drum-head and convert them into vibrations of greater force, so that they may properly affect the liquid which fills the spaces of the inner ear. This is done by the *tympanic membrane*, or drum-head, and *the chain of bones*.

The tympanic membrane, or drum-head.—The chief agency for intensifying the vibrations is the drum-head. In shape and structure it is admirably adapted to this end. It is composed of three layers, the outer one being a continuation of the skin which lines the meatus, and the inner one being the mucous membrane which lines the whole interior of the drum. The middle layer is the essential one. It is composed of radial and circular fibres of connective tissue which are always stretched and kept tense by a muscle which pulls on the handle of the hammer. Thus the membrane is made to take the shape of a funnel with its apex at the point of attachment to the *hammer*. The sides of this funnel are stretched, but do not pass straight from the rim to the apex. They apparently sag towards the centre of the funnel, thus being convex towards the meatus. This is important, for it is chiefly by this arrangement that the force of a sound-wave is intensified. The mechanical principle involved may be easily understood by reference to the diagram, Fig. 145, which represents the outlines of the drum-head. The radial fibres are stretched from the apex to the base of the cone, and the circular fibres keep the sides convex towards the centre. Now, any pressure against the inner sides of *a* and *b* in the direction of the arrows would relieve their tension and permit the apex to move towards *c*, in which direction it is constantly pulled by the handle of the hammer. When the pressure ceases, the apex will at once be brought back to its former position by the tension of *a* and *b*. The sides may move back and forth through a considerable distance, while the apex will, as a result, be moved back and forth only a very *short distance*, but with proportionately *greater force*. Thus sound-waves may exert a considerable force on the handle of the hammer.

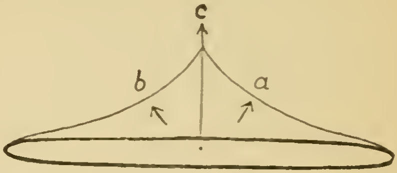

FIG. 145.—Diagram showing mechanical action of tympanum.

The ossicles of the ear-drum.—The function of the three bones in the drum is to transfer the vibrations from the drum head to the inner ear, and to still further intensify the vibration at a sacrifice of distance moved.

The bones are held in place by ligaments, and are closely jointed to each other. They act together as a lever, having its fulcrum at *F* (Fig. 146). Thus the power arm of the lever is the distance from the vertex of the drum-head to *F*, while the resistance arm is only from *F* to the end of the long process of the anvil. The power arm of this lever is found to be one and one-half times as long as the resistance arm, and so the force is increased one and one-half times and the distance moved is made proportionately less. The back and forth movement of the stirrup does not exceed about $\frac{1}{250}$ of an inch.

The Eustachian tube.—The pressure of the air within the drum should be the same as that of the air outside. Air-pressure is constantly changing at any point on the earth, as is shown by the changes in the barometer, and also the pressure is different at different altitudes.

In order that man might retain his power of hearing while he is subject to these frequent changes, it is necessary that a tube connect the outside air with the drum. This is the purpose of the *Eustachian tube*, which is shaped like a trumpet, and is connected by its small end to the drum and by its large end to the pharynx. It is made of thin cartilage, so that it usually stands open.

Air may be forced from the mouth into the drum, or may by suction be drawn from it. In either case a difference of air tension is caused within and without the drum, and hearing becomes indistinct and confused. This will continue, though nose and mouth be now open, for the large opening of the tube is loosely closed by certain muscles in the pharynx which are concerned in the act of swallowing. When we swallow, then, the passage through the tube is free, and the equal tension of the air is restored.

When the pharynx is inflamed, as from colds, the Eustachian tube often becomes partly or wholly closed, thus causing a roaring and feeling of fulness in the drum.

Openings into the drum.—The Eustachian tube is the only opening through which substances, such as gases and liquids, can pass into and from the middle ear, or drum. There are three other openings, however, through which waves or other disturbances may easily pass in or out. These are all covered with thin membranes. One is the tympanic membrane, which has already been described, and the other two are the oval and circular windows which open into the internal ear. There are, also, openings, near the top of the drum, into air-chambers in the temporal bone. These chambers are called the *mastoid cells.*

Size of parts of the drum.—The student is apt to get the idea that the parts just described are much larger than they are in fact. A statement of the size of a few parts may assist in getting a correct idea of the size of all.

The tympanic membrane is not quite one-half inch in diameter. The length of the malleus, or hammer, is nearly seven-tenths of an inch. The total length of the stapes, or stirrup, is not quite two-tenths of an inch. The weight of all the bones together is only a few grains.

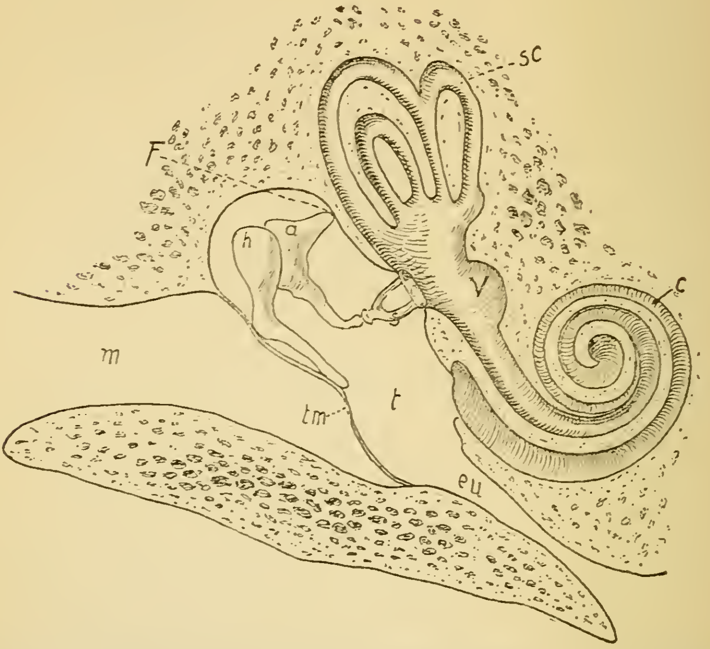

FIG. 146.—Diagram showing the relative position of the three parts of the ear. *m*, meatus; *tm*, tympanic membrane; *t*, tympanum; *h*, malleus; *a*, incus; *s*, stapes; *o*, oval window; *eu*, Eustachian tube; *sc*, semicircular canals; *v*, vestibule; *c*, cochlea; *F*, fulcrum of the lever formed by the ossicles.

The internal ear.—The relation of the three parts of the ear may be learned by an observation of the diagram in Fig. 146. The sound-waves pass in through the meatus, *m*, and cause a vibration of the tympanic membrane, *tm*. The chain of bones acts as a lever with the fulcrum at *F*, and transmits the vibrations to the oval window, *o*, the entrance into the third division of the ear.

The internal ear is called the *labyrinth* because of its many winding passage-ways. The *labyrinth* is an irregular chamber in the hard part of the temporal bone. It may be described as composed of three parts,—the *vestibule*, the *semicircular canals*, and the *cochlea*. These are simply cavities in the hard bone. If some plaster of Paris were poured into these cavities and allowed to remain there till it would harden and form a cast, it would, when cut out, have the form shown in Fig. 147. These cavities are called the *osseous labyrinth*, as distinguished from another which is contained within it and known as the *membranous labyrinth*.

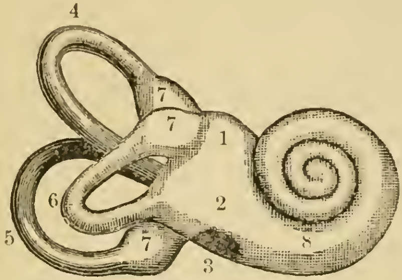

FIG. 147.—The right labyrinth, viewed outwardly in front, magnified two and a half times. 1, vestibule; 2, oval window; 3, round window; 4, superior semicircular canal; 5, posterior semicircular canal; 6, inferior semicircular canal; 7, ampullæ; 8, cochlea.

The osseous labyrinth.—The *osseous*, or *bony*, vestibule lies between the cochlea and the semicircular canals. On its front side, that is the side towards the tympanum, is the *oval window*, which is covered with a membrane to which the stirrup is attached. Below is the *round window*, covered with a thin membrane which separates the liquid within the vestibule from the air in the middle ear.

In the back part of the vestibule are five holes, which are the openings into the *semicircular canals.* These canals are not complete circles, but arch over somewhat in the shape of a horseshoe. both ends opening into the vestibule. Two of the ends unite and pass together into the vestibule. and hence there are but five openings as seen from within the vestibule.

The plane of each of the semicircular canals is at right angles to the planes of the other two. just as the three faces of a cube that meet at one corner are each at right angles to the other two. This is important, as will be explained later on.

The osseous cochlea is a spiral canal resembling in shape the interior of a snail shell, and hence its name.

The axis of the cochlea is a conical pillar of bone called the *modiolus.* The canal passes spirally around the modiolus, making two and one-half turns.

A thin spiral shelf of bone, called the *spiral lamina*, projects from the modiolus much as the blades of steel project from the central axis of an augur. The spiral lamina extends about half-way across the canals, as shown in Fig. 148. The remaining distance across the canal is filled in by the membranous cochlea. which will later be described. Thus, the osseous canal is divided into two nearly equal channels throughout its whole length. The upper one communicates at its base with the vestibule, and so is called the vestibular passage.

The base of the lower one is over the round window, through the membrane of which it may communicate with the tympanum, and so it is called the *tympanic passage*. The two are connected only by a small orifice at the top of the canal.

The whole labyrinth is lined with periosteum, which secretes a fluid called *perilymph*, with which the labyrinth is filled.

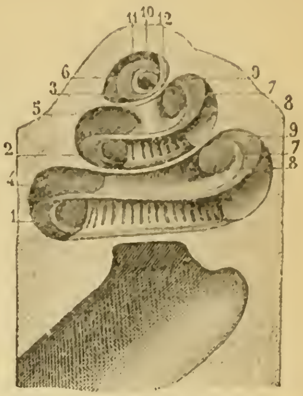

FIG. 148.—The cochlea laid open, its summit turned upward, magnified three diameters. 1, 2, 3, the tympanic passage; 4, 5, 6, the vestibular passage; 7, 8, osseous spiral lamina; 9, membranous spiral lamina; 10, orifice of communication of the two passages at the summit of the cochlea; 11, 12, termination of the osseous and membranous spiral laminæ.

The membranous labyrinth.—The *membranous labyrinth*, shown in Fig. 149, is nearly the form and shape of the bony labyrinth in which it is enclosed. It occupies about two-thirds of the space in the bony cavity and partly floats in the perilymph. It is composed of three parts, having names of the corresponding parts of the bony labyrinth, and is filled with a liquid called *endolymph*.

In the membranous vestibule are two pouches, the smaller called the *saccule*, and the larger, the *utricle*.

These are fastened together, but do not communicate except through the Y-shaped tube called the *vestibular aqueduct*, shown in Fig. 149, 5.

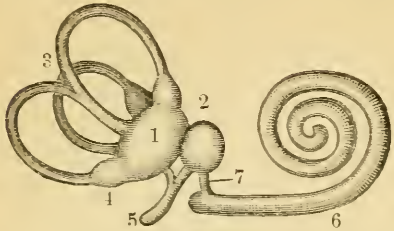

FIG. 149.—The membranous labyrinth, magnified two and a half times. 1, utricle; 2, saccule; 3, semicircular canals; 4, ampullæ of semicircular canals; 5, vestibular aqueduct; 6, membranous cochlea; 7, canal connecting saccule and membranous cochlea.

Connected to the utricle are the three membranous semicircular canals which are lightly attached along one side to the bony canal.

A division of the auditory nerve enters the saccule, utricle, and semicircular canals, and at these points the membrane closely adheres to the bone. At the entrance to the semicircular canals and on spots in the membranous labyrinth are epithelial cells of a peculiar formation, known as *hair-cells*. These are directly surrounded by a liquid somewhat thicker than the endolymph, and in it are embedded numerous small crystals of calcium carbonate, known as the *otoliths*. In these hair-cells the nerve-fibres of the vestibular branch of the auditory nerve end. These, however, probably have no part in producing the sensations of sound.

The membranous cochlea is a three-sided tube with one side attached to the bony wall of the canal and the opposite corner to the edge of the spiral lamina. Thus, it completes the division of the bony canal into two parts. In fact, the canal of the cochlea may be considered as divided into three spiral tubes,—the *vestibular* tube, the *tympanic* tube, and the *membranous* tube between the other two and on the outer side of the canal. In Fig. 151 is shown a cross-section of one of the bony canals of the cochlea.

The membranous canal, or passage, is filled with endolymph and winds about with the other passages to the top of the cochlea, where it is closed. Its only opening is at its base through a small canal into the saccule. See Fig. 149, 7.

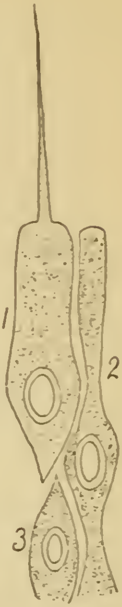

Fig. 150.—Diagram of acoustic epithelium. 1, acoustic hair-cell; 2, supporting cell; 3, immature cell.

The organ of Corti.—The membranous canal of the cochlea is the most essential part of the organ of hearing. On its floor is the organ of Corti, where the nerve-fibres receive the impulses that arise from the vibrations of sound-waves.

By reference to Fig. 152 it is seen that a membrane is stretched from the edge of the spiral lamina at *O* to the wall of the cochlea at *W*. This is the *basilar membrane*. Upon it stand the rods of Corti and the hair-cells.

The rods are comparatively stiff and are arranged in an inner and an outer row. The tops of the two rows are bent towards each other and connected, thus forming the tunnel, *A*. The base of the rods are attached by broad feet to the basilar membrane. About 4500 pairs of these rods are placed along the course of the canal.

On the inner side of the tunnel formed by the rods is a row of hair-cells, and on the outer side there are three or four rows of the same kind of cells. (Fig. 152.)

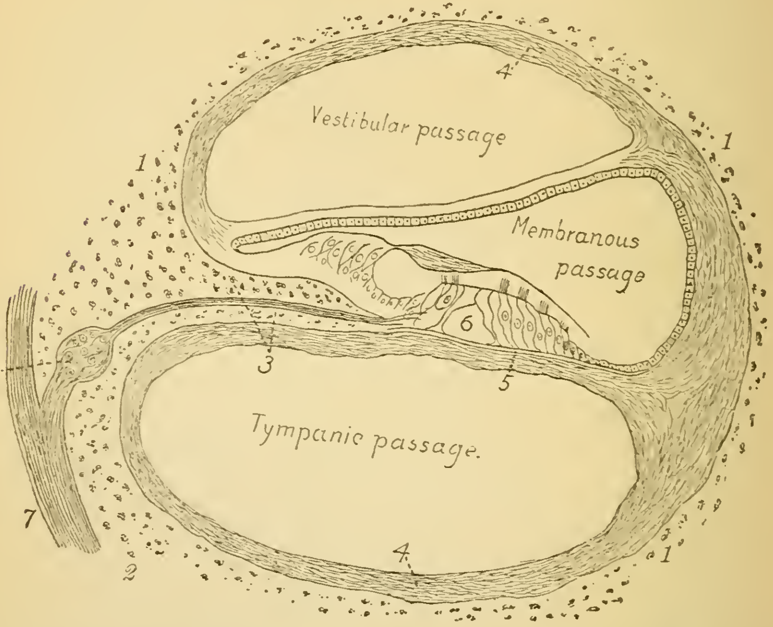

FIG. 151.—Cross-section of one of the canals of the cochlea, showing the three passages. 1, bony wall of cochlea; 2, position of modiolus; 3, bone of spiral lamina; 4, periosteum; 5, basilar membrane; 6, under the arch of Corti's fibres; 7, cochlear nerve; 8, ganglion.

A fibre of the auditory nerve is attached to each of the hair-cells. There are, in the cochlea, about 16,000 of these cells.

The basilar membrane is stretched from side to side, but lies loose in a direction along the canal. The layer of this membrane to which the rods and hair-cells are attached is striped by fibres from side to side. These fibres differ in length, the shortest being at the base of the cochlea, and the longest at the top. The length varies from about .00162 inch for the shortest to about .01949 inch for the longest. Thus, the latter is a little more than twelve times the former.

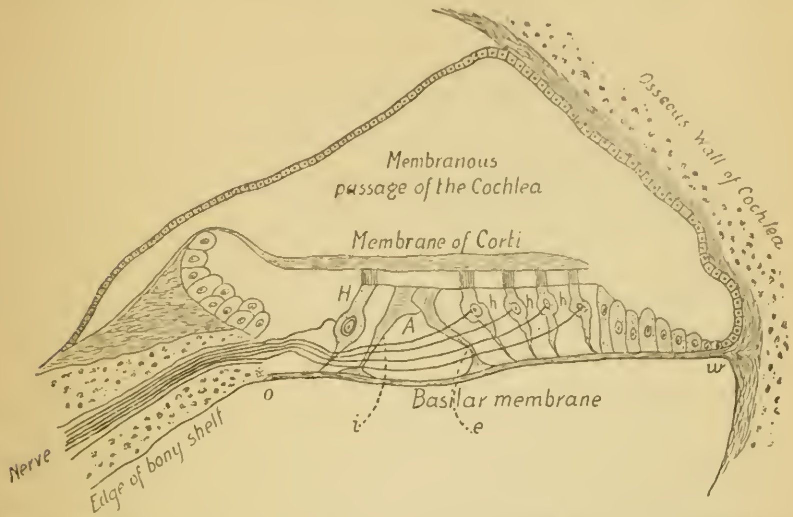
Membranous passage of the Cochlea
Membrane of Corti
Osseous wall of Cochlea
H
h
h
h
h
A
w
o
Basilar membrane
i
e
Nerve
Edge of bony shelf

FIG. 152.—Diagram of a section of the membranous cochlea, showing position and arrangement of Corti's organ. *i* and *e*, interior and exterior rods of Corti; *A*, tunnel formed by the arching rods; *H*, interior row of hair-cells; *h*, *h*, *h*, exterior row of hair-cells.

Function of the cochlea.—The cochlea alone is the organ of hearing. All sense of sound and music arises in the cochlea.

When the stapes sets up a vibratory motion, or quiver, in the perilymph, the motion is easily communicated to the delicate membranes about the membranous cochlea, and the endolymph partakes of the same vibrations. The fibres of the basilar membrane, which have the proper length to vibrate in sympathy, will be most agitated. The rods and hair-cells which are attached to these fibres will convey the motion to the terminals of the nerve-fibres.

A nervous impulse thus started will travel along the auditory nerve to the medulla oblongata and thence by other neurons to the seat of perception in the cerebrum.

The difference in the length of the fibres of the basilar membrane is sufficient to explain the ear's ability to distinguish all differences of pitch in music, even when the difference is very slight.

The ear is most sensitive in the first octave above middle C. Here the ear of some trained musicians have been able to distinguish a difference of one-half a wave per second, thus making about 1000 distinguishable notes in the octave.

Function of the round window.—Since the whole labyrinth is enclosed in a hard, bony cavity and is filled with a liquid which is almost incompressible, it is necessary to have some spot which will yield. The purpose of the *round window* is to yield to pressure upon the liquid in the labyrinth. When the stapes presses inward, the pressure is communicated along the vestibular passage of the cochlea and then across to the tympanic passage and down to the oval window, which is thus made to bulge out into the tympanum A decrease of pressure in the labyrinth would cause the round window to bulge in. The oval window thus permits greater freedom of vibration in the liquid.

Function of the semicircular canals.—The semicircular canals and vestibule probably have no part in producing the sensation of hearing.

The position and structure of the canals as well as many experiments which have been made all go to show that their function is to give a *sense of equilibrium.* By this sensation it is possible for us to maintain any desired posture of the body. The least tendency to fall to one side or the other is at once made known and checked by the use of the proper muscles.

The planes of the three canals are each at right angles to the other two, and hence any motion of the head will cause a motion of the liquid in one or more of the canals. This motion affects the auditory hair-cells to which the nerve-fibres are attached, and thus a nervous impulse is sent on the vestibular branch of the auditory nerve to the medulla and on to the cerebellum.

Experiments made with birds and other animals show that when the semicircular canals are injured, the animal will fall from side to side when it attempts to move. All sense of balance and ability to co-ordinate muscular movement appear to be gone. The nerve terminals in the vestibule are probably associated in function with those of the semicircular canals.

Care of the ear.—The inner ear is so well protected that it needs no care except in so far as it shares in the general health or weakness of the whole system. It is, however, capable of a very high degree of culture and refinement.

A great deal of the pleasure and enjoyment of this world is derived from music, but only those whose ears and minds have been educated to that which is best in music can get the full enjoyment from it.

The external and middle ear open to the outside, and so can receive direct care at our hands.

Sometimes ear-wax in excess will gather in the meatus or collect on the tympanic membrane. In such cases it is always better to consult a physician, for the attempt to get it out with a pinhead or other hard instrument may cause a still more serious injury.

Insects sometimes get into the meatus, but seldom do any injury. A little warm water or sweet oil poured in will usually cause them to come out, or a physician can remove them with proper instruments.

The middle ear is probably the greatest source of trouble and needs our greatest care.

When the throat is inflamed and sore, there is always danger that the inflammation may be communicated to the Eustachian tube and thence into the middle ear.

An inflammation of the linings of the middle ear may cause serious illness or even death. Not only the middle ear proper may be affected, but also the mastoid cells in the temporal bone. Here, back of the ear, pus may collect where there is only a very thin partition of bone between it and the brain. In that case it may be necessary to bore through the outer layer of the skull to the pus and thus drain it off.

Colds often "settle" in the middle ear and cause a great deal of pain and annoyance.

SENSE OF TOUCH

Location and purpose of the touch organs.—The whole surface of the skin, and the mucous membrane at points of entrance to the body, are covered with minute conical elevations called the papillæ. These are on the outer surface of the true skin and are covered by the epidermis. In some regions of the skin the papillæ are very numerous, and on the palmar surface of the hands and fingers they are arranged in rows which can be plainly seen.

Some of the papillæ contain only loops of capillary blood-vessels and lymphatics, but others contain a special organ called the *tactile corpuscle.*

The purpose of the tactile corpuscle is to give us knowledge by contact with outside bodies.

The eye and the ear are the two great organs, of about equal importance, through which we gain knowledge by means of waves coming from the objects that are seen or heard.

The sense of touch is third in importance.

The tactile corpuscle.—Many of the papillæ contain an oval-shaped body called the *tactile corpuscle.* These are found on the palms and soles, particularly on the fingers and toes, where about one out of every five of the papillæ contains this organ. One, two, or three nerve-fibres may enter directly into the corpuscle or after winding three or four times around it.

Other tactile end organs which are distributed generally in the skin of the body are the *end bulbs*. These are small collections of epithelial cells to which nerve-fibres are connected. They are quite as sensitive as the corpuscles described above.

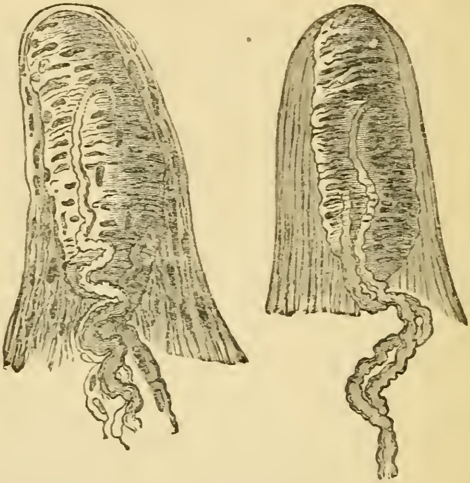

Fig. 153.—Two tactile papillæ from skin of finger. Touch corpuscle within and nerve-fibres below.

The Pacinian corpuscle.—The Pacinian corpuscles are small, oval-shaped, white bodies found in many parts of the alveolar tissue beneath the skin. They are formed of thirty or more tunics of connective tissue and contain at the centre a terminal of a nerve-fibre. Their function is not clearly understood.

Sensitiveness of different parts of the body.—By laying the two points of a compass upon the skin at various places, a test can easily be made of one's ability to distinguish two points of contact. By bringing the points of the compass closer and closer together, a distance will be reached where the two points are judged as one. This, then, is a test of the closeness and delicacy of the tactile organs.

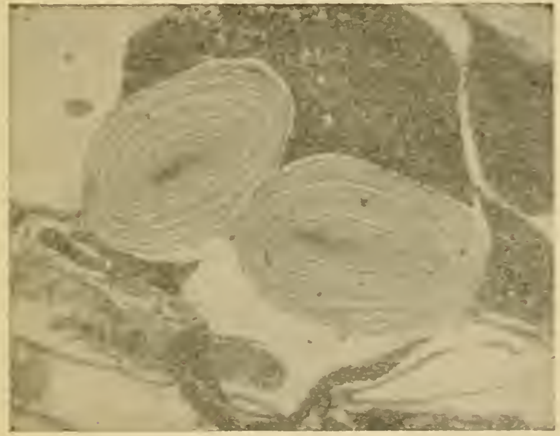

FIG. 154.—Two Pacinian corpuscles. (Microphotograph.)

The place where the two points may be most nearly together, and yet be felt as two, is on the tip of the tongue. The place of least sensitiveness is in the middle of the back. Some of these tests show that this distance on the tip of the tongue is about $\frac{1}{25}$ of an inch; on the end of the finger about $\frac{1}{12}$ inch; on the lip, $\frac{1}{6}$ inch; on the forehead, nearly one inch; and on the upper arm and back, about two inches.

Path of the nervous impulse.—The nervous impulses resulting from touch are carried chiefly by the sensory fibres of the spinal nerves to the spinal cord. There a reflex action may occur and a motor impulse be at once sent out. This happens when the touch is such as to indicate an injury of the part touched.

At the same time the sensory impulse is carried by other neurons to the proper centre in the cortex of the cerebrum. There not only do we perceive that the body has been touched, but the point is exactly located, and other motor impulses may be sent out from that centre.

Training of the sense organs.—The organs of touch, particularly those in the ends of the fingers, are capable of training, so that they will be a valuable means of gaining information in regard to outside objects. The sense of touch may be more reliable than any of the other senses, as in judging the shape and surface of objects, or the texture of fabrics. One who is blind soon learns to read by moving the fingers along a row of raised letters, and can quickly recognize a friend by passing the hand over the face.

Miss Helen Keller has not been able to see or hear since she was two years old, and yet she has been able, through the sense of touch, to become highly educated.

SENSE OF SMELL

The nose.—The sense of smell is located in the nose. The large cavity in the skull, between the two orbits of the eyes, is occupied by the nasal passages. The cavity is divided into two compartments by a partition which is bone in the posterior part, but is continued as cartilage towards the end of the nose.

Both passages open freely to the air in front and to the pharynx in the rear. Both passages are covered with mucous membrane, a large surface being presented not only by the plain walls, but also by the three turbinated bones which project from the exterior sides of the nostrils

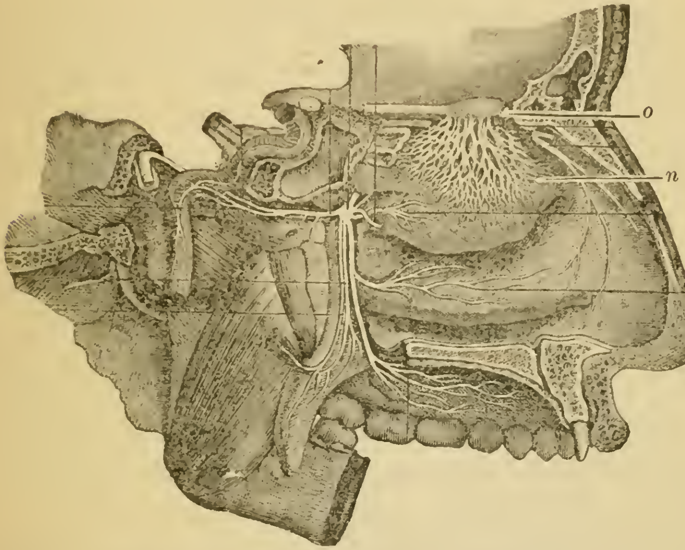

FIG. 155.—*o*, olfactory bulb; *n*, nerves descending to the mucous membrane.

The lower part of the nose cavity is called the *respiratory region*, for it is properly fitted for receiving air into the body, as has been explained under the subject of respiration. Here the lining membrane is composed of ciliated epithelium. The upper part of the cavity is called the *olfactory region.*

The olfactory region.—In the upper part of the nostrils the organ of smell is located. Here the surface is also covered with epithelial cells, but they are not ciliated and their construction is peculiar. Part of them contain an oval nucleus from which long projections extend on each end, one coming to the surface of the membrane and the other extending back to a nerve-fibre. Numerous cells of this kind reach the free surface of the mucous membrane at one end, and connect with a nerve-fibre at the other.

Numerous glands in this region keep the surface constantly moist.

The act of smelling.—Odors which arise from substances are carried in the air. In ordinary breathing, a small area of the olfactory region is always exposed to the air passing through the nostrils, but by "sniffing," the air is admitted to a much larger area and many more of the nerves of smell are affected.

The fine particles suspended in the air must fall upon the moist mucous membrane and be dissolved, or, if a gas, must enter into solution before they produce any effect.

An impulse started by this stimulus will travel to the olfactory bulbs, as shown in Fig. 155, and will there be taken up by other neurons and carried to the seat of perception in the temporal lobes of the cerebrum.

The use of the smelling sense.—In many of the lower animals, as in certain breeds of dogs, the sense of smell is the most important of the five senses.

In man this sense is often underestimated. The primary purpose is to give us knowledge of any harmful substance in the air which we breathe. As a secondary use, it enables us to distinguish objects by their odor, and to give pleasure in the presence of pleasant odors. The impressions made by the sense of smell appear to be very distinct and lasting.

When the same odor is breathed through the nostrils for a time, it ceases to affect the organ of smell. When one comes from fresh air into a close room, the bad condition of the air is very noticeable at first, but after a few breaths the ability to distinguish the foul from the pure air is lost, until a change of air is again made. The air in Mammoth Cave is quite free from the floating particles which are plentiful in the air we ordinarily breathe. After a few hours in the cave, one will, on coming out into the air again, feel a keen pain in the nostrils until he becomes accustomed to the outside air.

Since the mucous membrane of the nostrils is the first to be exposed to the air which we inhale, it will intercept most of the particles which are floating in the air, and thus it is often irritated and inflamed, and a catarrhal condition is brought about, which is very destructive to the organ of smell.

THE SENSE OF TASTE

Location and structure of the organs of taste.—Just as the organ of smell is a guard at the gateway to the lungs, so the organ of taste is a guard at the gateway to the stomach.

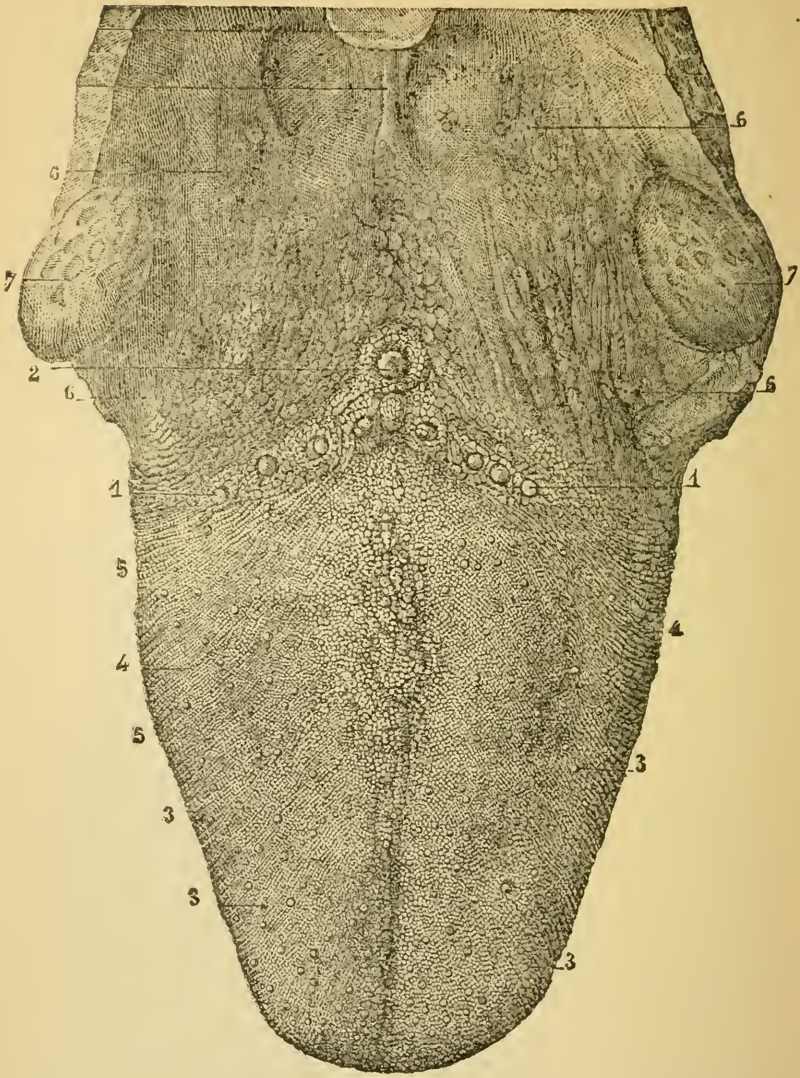

FIG. 156.—View of the dorsum of the tongue. 1, 2, V-like row of the circumvallate papillæ; 3, fungiform papillæ; 4, 5, conical papillæ; 6, 6, floor of the fauces, with numerous lymphoid follicular glands; 7, tonsils; 8, summit of the epiglottis.

The organs of taste are found in various parts of the mouth, but chiefly on the palate and tongue. On the tongue numerous little eminences may be plainly seen with the naked eye. These are papillæ, which contain the organs of taste. On the front part of the tongue there are small conical projections called *filiform papillæ*. On the middle region they are larger and appear like a fungus growth, and so are called *fungiform papillæ*. On the back of the tongue are eight or ten large elevations arranged in a V form with the vertex of the V towards the throat. Each of these appears to be surrounded with a ditch and a wall, and so are called *circumvallate papillæ*.

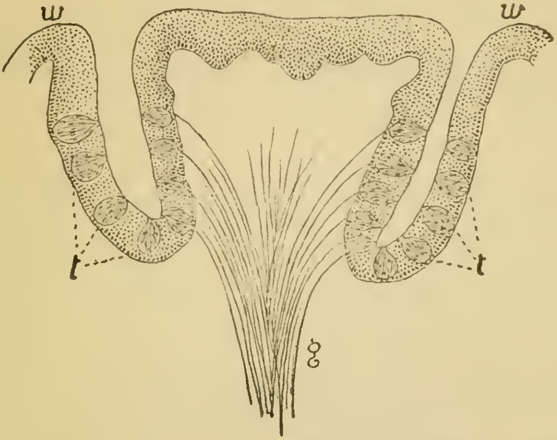

FIG. 157.—Cross-section of a circumvallate papilla. *t*, taste-buds; *w*, wall; *g*, nerve-fibres connected to taste-buds.

Within the latter two kinds of papillæ are clusters of cells called *taste-buds*. Within the buds are several cells which project from the end of the bud, and to which fibres of nerves are attached. These are the *taste-cells*.

These buds are arranged in the sides of the depressions around the circumvallate papillæ as shown in Fig. 157. They are also found in the fungiform papillæ.

Conditions and kinds of taste.—A substance must be in solution before it can affect the taste-cells. If the tip of the tongue be wiped dry and some dry sugar be touched to it, no taste will follow until the tongue again becomes moist. By the sense of taste it is possible to distinguish sweet, sour, bitter, and salt.

The tip of the tongue is best adapted for receiving a stimulus from sweet substances, and the sides and back of the tongue for sour or bitter substances.

Cultivation of taste.—By proper attention the sense of taste may be made very acute. Some persons are paid good salaries for doing nothing but determine the quality of liquors by their cultivated sense of taste. The constant use of tobacco and alcoholic liquors will, however, so blunt this sense that most substances will have no taste or will all taste alike.

Smell and taste are closely associated and often confused. The odor from substances in the mouth may easily pass up, from the throat into the nostrils, and thus we attribute to the sense of taste what belongs to the sense of smell. If while eating an onion the nostrils be held shut, the so-called onion taste will not be perceived.

QUESTIONS FOR REVIEW.

1. What are the special senses?

2. Name and describe five general senses.

3. What is the great advantage of the five special senses?

4. What are the two great media through which stimuli reach the special senses,—the eye and the ear?

5. Make a sketch and locate the parts of the eye.

6. What is the use of the front parts of the eye?

7. Describe the cornea.

8. When is light refracted?

9. Make a drawing to show how rays of light are affected by the cornea.

10. Describe the iris.

11. What is the use of the iris?

12. Describe the crystalline lens.

13. What is the chief use of the lens?

14. Explain how the convexity of the lens is changed for different distances.

15. When is the eye emmetropic?

16. Explain the condition of the myopic eye.

17. When is the eye said to be hypermetropic?

18. What kind of glasses must be used for near-sighted or far-sighted eyes? Why?

19. How is the eye moved?

20. Explain the cause of cross-eyes.

21. What is the function of the posterior parts of the eye?

22. What are the three coats of the eye? Which is most essential? Why?

23. Describe the retina.

24. What are the rods and cones, and where are they placed?

25. Locate and describe the yellow spot.

26. Where is the blind spot?

27. What is the size of the image on the retina?

28. How close can two points be together and still be seen as two?
29. Describe the optic nerve.
30. How are two eyes better than one?
31. Explain the perception of color.
32. Explain all the ways by which the eyes are protected.
33. What care should be taken of the eyes?
34. How do alcohol and tobacco injure the eyes?
35. Explain the nature of air-waves.
36. How fast does sound travel? Light?
37. What are the three parts of the ear?
38. Describe the pinna and give its use.
39. Describe the meatus.
40. Why is the middle ear called a drum?
41. Name the parts of the drum.
42. Describe the structure and use of the tympanum.
43. Make a drawing of the three bones and describe them.
44. How do the bones increase the force of the vibrations?
45. What is the use of the Eustachian tube?
46. What are the openings into the drum?
47. How large is the drum?
48. Where is the labyrinth located, and what are its three parts?
49. Describe the osseous labyrinth.
50. Describe the membranous labyrinth.
51. How do the nerves end in the utricle, saccule, and semicircular canals?
52. Describe the membranous cochlea.
53. Give a full description of the organ of Corti.
54. What is the function of the cochlea?
55. Of what use is the round window?
56. What is the function of the semicircular canals?
57. How can the ear be properly cared for?
58. Where are the organs of touch located?
59. Describe a tactile corpuscle.
60. What is a Pacinian corpuscle?

61. What part of the body is most sensitive to touch? What least? How can this be determined?

62. How do we know when we are touched?

63. Describe the structure of the nostrils.

64. Explain the use of "sniffing."

65. Of what advantage is a keen sense of smell?

66. Where are the organs of taste located?

67. Describe the taste-buds.

68. What are the four taste sensations?

69. How are smell and taste confused?

70. Which of the special senses do you prize most highly? Why?

EXPERIMENTS.

1. Secure at the butcher-shop two or three eyes of the ox or sheep. Closely examine one of them, noting the tough, white sclerotic coat on the outside; the point of entrance of the optic nerve; the bulging, transparent cornea on the front; the iris and pupil beneath. Cut through the cornea, noting its thickness and the limpid aqueous humor within. Find the crystalline lens and notice the curvature of its two sides. Open the back part, noting the three coats and the thick vitreous humor within.

2. Hold a mirror close before the face and notice the size of the pupil. Shade the eyes from the light, and the iris can be seen to draw back on all sides, thus making the pupil larger. Suddenly admit more light to the eyes and the pupil will grow smaller.

3. Make on a piece of white paper two black spots about three inches apart. Hold the left eye shut and look with the right eye steadily at the spot on the left. By varying the distance a position of the paper can easily be found where the image of the spot on the right side will fall upon the place where the optic nerve enters the right eye. This is the blind spot, and so the image makes no impression, that is, cannot be seen.

4. Try to see a whole line of this page distinctly without moving the eyes Try a single small word. Try a single letter. Only the images of very small objects can be wholly contained in the yellow spot. Hence the need of many muscles to freely move the eyes from point to point.

5. Use a pocket microscope as a lens. Hold it near the wall of a room and

note the image of a window or burning lamp. This is the action of the cornea of the eye.

6. Look through a window and adjust the crystalline lens so that some object, as a tree or a house, can be seen distinctly. At the same time the window can be seen, but only indistinctly. Now readjust the lens so that the window can be distinctly seen, and then the objects beyond can be seen only indistinctly.

7. The image on the retina of an eye may be seen by cutting away the two outside coats from the back of the eye of an ox. The thin retina must be carefully left in place. If the eye thus prepared be now pointed towards a candle or lamp, and the light be screened from the eyes of the observer, an inverted image can be seen on the retina.

8. Rapidly rotate a wheel and notice that the spokes will all apparently be blended. The space between the spokes and the spokes themselves unite to form a transparent disc. This is because a retinal impression lasts for about one-seventh of a second. If the rotating wheel is seen by the light from a stroke of lightning, it will appear to be standing still.

9. Prepare two discs of card-board, about six inches in diameter, one blue and the other yellow. Hold the blue one against a white background and look steadily at it for a minute, then suddenly jerk it away. A yellow disc will be seen in its place. Try the same with the yellow one, and a blue outline of the disc will appear on the white background.

These are two complementary colors and will when mixed produce white. When the eye was fatigued by looking at the yellow it was still sensitive to its complement,—the blue. When it was fatigued by the blue it could more distinctly see the yellow.

10. Close the nose and mouth and blow air through the Eustachian tube into the ear-drum. Notice that hearing is then less distinct.

11. Utter quick, explosive notes into a piano and notice how it returns the same note whatever the pitch may be. By this illustrate the sympathetic action of the fibres in the basilar membrane of the cochlea.

12. Use a compass with blunt points and try on various parts of the body how close together the points may be and yet be felt as two points.

13. It is an interesting test of one's ability to locate the spot where he has been touched, if one will close his eyes while another touches him with the

point of a pencil. Then see how nearly the one who is touched can locate the exact spot.

14. Cross two fingers and roll a bullet or small round body between them. One will appear as two.

15. Place the same number of shot in each of two bottles. Balance one bottle in each hand to determine, by the muscular sense, the weight. Then have some one change a few shot from one bottle to the other and then try to determine which bottle is the heavier. By continued practice the muscular sense becomes very acute.

16. Prepare three vessels of water. One hot, one cold, and a third lukewarm. Place one hand in the hot water and the other in the cold. After a short time transfer both to the lukewarm water, and it will feel cold to the hand that was in the hot water, and warm to the hand that was in the cold water.

GLOSSARY

A LIST of physiological terms likely to be mispronounced.

It is a good plan to have the class pronounce this list of words occasionally until the pupils become accustomed to the sounds and accents.

Ab do'men
Ad'i pose (ad'i pōs)
Af'fer ent
Al bu'men
Al ex'ines (al eks'ins)
Al i men'ta ry
A mœ'ba (a mē ba)
Am phib'i a (am fib'e ah)
A nat'o my
An ti tox'in (an te tok'sin)
A or'ta
Ap pen di ci'tis
A'que ous (ā'kwe us)
Ar ach'noid (ar ak'noid)
Ar e'o lar
Ar'ter y
Ar tic'u lar
Au'di to ry
Au'ri cle (aw'rik l)
Au ric'u lo ven tric'u lar

Bac te'ri a
Bac te ri ol'o gy
Bās'i lar
Bi'ceps (bi'seps)
Bi cus'pids
Bron'chi (bron'ki)

Cæ'cum (se'kum)
Cal'o rie (kal'o re)
Can al ic'u li
Can'cel lous
Ca'nines
Cap'il la ries
Car bo hy'drates
Car'di ac
Car ti lag'in ous (g = j)
Ca tarrh'al
Cen'tral fo'vea (fo've ah)
Cer e bel'lum
Cer'e bro spi'nal
Cer'e bro spi'nal men in gi'tis
(Ser'e bro spi'nal men in ji'tis)
Cer'e brum (ser'e brum)
Cer'vi cal (ser'vi kal)
Cho'roid (ko'roid)
Chro'ma tin (kro'mat in)
Chyle (kīl)
Chyme (kīm)
Cil'i a ted
Cir'cum val'late
Co ag u la'tion
Coc'cyx (kok'six)
Coch'lea (kok'le ah)
Con'cha (kong'kah)

Cor′ne a (kor′ne ah)
Cor′pus cal lo′sum
Cor′pus cle
Cra′ni um
Crys′tal line
Cy clo sto′ma ta

Deg lu ti′tion
De lir′i um tre′mens
Den′drites
Den′tine (den′tin)
Di′a phragm (di′af ram)
Diph the′ri a (dif the′re ah)
Dip so ma′ni a
Dis sec′tion
Du o de′num
Du′ra ma′ter

Ef′fer ent
E lec trol′y sis
Em me trop′ic
E mul′si fied
En am′el
En do car′di um
En′do lymph (en′do limf)
En dos′te um
En vi′ron ment
Ep i glot′tis
Ep i the′li um
E qui lib′ri um
Er′go graph
Eu sta′chi an (u sta′ke an)
E vap o ra′tion
Ex′cre to ry
Ex ha la′tion

Fah′ren heit (Fah′ren hīt)
Fas ci æ (fash′e e)
Fas cic′u li (fas ik′u lī)
Fau′ces (faw′sēz)
Fer men ta′tion

Fi brin′o gen
Fib′u la
Fil′i form
Fis′sure (fish′ūr)
Fla gel′la (fla jel′la)
Fo ra′men
Fun′gi form (fun′ji form)

Gan′gli a (gang′gle a)
Gly′co gen (gli′ko jen)
Gus′ta to ry
Gym na′si a

Ha ver′si an (Ha ver′zhan)
Hem o glo′bin
Hi′lum
Hy dro chlo′ric
Hy dro pho′bia
Hy′gi ene
Hy per me trop′ic
Hy po gas′tric

Il e o col′ic
Il′e um
In ci′sors
In′cus (ing′kus)
In fun dib′u la
In ha la′tion
In nom i na′tum
In sal i va′tion
In som′ni a
In ter cos′tal
In tes′tine (in tes′tin)
In vol′un ta ry

Je ju′num

Ki net′ic

Lab′y rinth
Lach′ry mal (lak′rim al)

Lac'te al
Lar'ynx (lar'ingx)
Lie'ber kuhn (le'ber kēn)
Lo'cal i za'tion
Lu'nu la
Lym phat'ics (lim fat'ics)

Mag ne'si um
Mal'le us
Mal pig'hi an (mal pig'e an)
Mas ti ca'tion
Mas'toid
Max'il la ry
Me a'tus
Me dul'la
Me dul'la ob lon ga'ta
Med'ul la ry
Mem'bra nous
Men in'ges (men in'jēz)
Mes'en te ry
Met a car'pal
Met a tar'sal
Mi cro pho'to graph
Mi cro scop'ic
Mo di'o lus
Mor'phine (mor'fin)
Mu'cous (mu'kus)
Mu ri at'ic
My op'ic
My'o sin

Neu'ron
Nic'o tine (nic'o tin)
Nu'cle us

Oc cip'i tal
O don'toid
Oe soph'a gus (e sof'a gus)
Ol fac'to ry
Os mo'sis
Os'se ous (os'e us)
Os'si cle (os'e kl)
Ō'to lith
Ox i da'tion

Pa cin'i an
Pan'cre as
Pa pil'læ (æ = ē)
Par'a lyzed
Pa ri'e tal
Pa rot'id
Pa tel'la
Per i car'di um
Per'i lymph
Per i os'te um
Per i stal'tic
Per i to ne'um
Per spi ra'tion
Pha lan'ges (fa lan'jēz)
Phar'ynx (far'inx)
Phos'pho rus (fos'fo rus)
Phys i ol'o gy
Pi'a ma'ter
Pleu'ra (plu'rah)
Pneu mo gas'tric (nu mo gas'tric)
Pneu mo'ni a (nu mo'ne ah)
Po tas'si um
Po ten'tial (po ten'shal)
Pro'te id
Pro'to plasm
Pro to zo'a
Pty'a lin (ti'a lin)
Pul'mo na ry
Py lo'rus

Rac'e mose (ras'e mōs)
Re frac'tion
Res'pi ra'tion
Res'pi ra to ry
Ret'i na

Sac'cule
Sar co lem'ma

Scle rot′ic (skle rot′ic)
Se cre′tion
Sem i cir′cu lar
Sem i lu′nar
Se′rous (se′rus)
Skel′e tal
Sta′pes (sta′pēz)
Sto′ma ta
Stri′a ted
Sub cla′vi an (sub kla′ve an)
Sub lin′gual (sub ling′gwal)
Sub max′il la ry
Sul phu′ric
Su′ture
Sym pa thet′ic
Syn o′vi al

Tet′a nus
Tho rac′ic (tho ras′ic)
Tib′i a
Tis′sue (tish′u)
Tra′che a (tra′ke ah)
Trans pi ra′tion
Tri chi′næ (trik i′nē)
Tu ber cu lo′sis
Tym′pan um
Ty′phoid

Un du la′tions
U re′a (u re′ah)
U rin if′er ous
U′vu la

Vac′u um
Val′vu læ con ni ven′tes
Vas o mo′tor
Ven′tri cle
Ver′te bra (plural æ = ē)
Ves′ti bule
Vil′lī
Vil′lus
Vit′re ous
Vol′un ta ry

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